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RUSSIAN DATA ON SPECTRAL REFLECTANCE

D. Steiner and Th. Gutermann

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RUSSIAN DATA ON SPECTRAL REFLECTANCE OF VEGETATION, SOIL AND ROCK TYPES

Final Technical Report

by

DIETER STEINER AND THOMAS GUTERMANN

Department of Geography
University of Zurich

November 1966

EUROPEAN RESEARCH OFFICE
United States Army

Contract no. DA-91-591-EUC-3863 / OI-652-0106

Contractor: Prof. Dr. Dieter Steiner
Department of Geography, University
of Zurich, Zurich, Switzerland

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Abstract

This report is the result of a survey of Russian literature dealing with the reflectance of vegetation, soil and rock types as basic information for the formulation of air photographic specifications. Techniques and methods of measurement are described and the most important findings are discussed. The text is supplemented by a collection of selected spectral reflectance data in graphical and tabular form as well as by a bibliography and an index of geomorphological, pedological and botanical terms with Russian and Latin equivalents.

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TABLES OF CONTENTS

INTRODUCTION

Data on the visible and the near infrared spectral reflectance of various elements of the earth's surface are of utmost importance for photo interpretation, because they permit the prediction of the separability of objects by means of photo tone on a given type of photographic material as well as the selection of appropriate film-filter combinations for a given purpose if special photographic coverages are to be flown.

In an earlier study of photo interpretation methods and techniques in the USSR[*] we found that a wealth of reflectance data is published in Russian literature mostly unknown to western researchers. The comprehensive works by E. L. Krinov (KRINEL47SOS, English translation: KRINEL53ERP)[**] and M. A. Romanova (ROMAMA62OTS, English translation: ROMAMA64ASS) are, except for some other smaller articles, the only basic papers which have been translated into English. What makes the Russian data especially interesting is the fact that numerous measurements have been taken from the air by means of spectrometric instruments mounted in a plane. We therefore felt that it would be worthwhile to compile a manual which would provide a description of the Russian investigations and the most important results there from. The present report is the product of this idea.

For this project we relied basically on literature available at the Department of Geography, University of Zurich, which has been building up a specialized library on photo interpretation for the past few years. As can be seen from the bibliography, where we have indicated the papers which were at our disposal, our source material was by no means complete. However, we believe that its evaluation will provide a representative cross section of the work on spectral reflectance done in the USSR. We have concentrated on compiling data for vegetation, soil and rock types. A major element of the earth's surface which is not covered in this report is water. The reader interested in reflectance of water will find a few examples included in our collection of spectral reflectance curves (Diags. 69 and 100) and a number of references in the bibliography (especially JANUDA61ISO, KALKAG58AMD and ZDANVG63AIM).

* See D. Steiner: Luftaufnahme und Luftbildinterpretation in der Sowjetunion. Erdkunde, vol. 17, no. 1/2, pp. 77-100, 1963 and D. Steiner: Technical Aspects of Air Photo Interpretation in the Soviet Union. Photogrammetric Engineering, vol. 29, no. 6, pp. 988-998, 1963.

** Alphameric codes refer to the bibliography.

All translations from the Russian have been done by the first author of this report and any errors are, therefore, his responsibility. We made use of the following general and technical dictionaries:

H.H. Bielfeldt: Russisch-Deutsches Wörterbuch. Veröffentlichungen des Instituts für Slawistik, Deutsche Akademie der Wissenschaften zu Berlin, 1119 pp., Akademie-Verlag, Berlin 1960.

N.N. Davydov: Botanicheskij slovar' - Russko-anglijsko-nemecko-francuzsko-latinskij (Botanical Dictionary - Russian-English-German-French-Latin). 335 pp., Gosudarstvennoe izdatel'stvo fiziko-matematicheskoj literatury (State Publishing House for Physical-mathematical Literature), Moscow 1962.

G.L. Gal'perin: Anglo-russkij slovar' po kartografii, geodézii i aerofototopografii (English-Russian Dictionary on Cartography, Geodesy and Aerial Phototopography). 546 pp., the same publisher as for Davydov, Moscow 1958.

O.S. Grebenshikov: Geobotanicheskij slovar' - Russko-anglo-nemecko-francuzskij (Geobotanical Dictionary - Russian-English-German-French). 226 pp., Akademija Nauk SSSR (Academy of Sciences of the USSR, Izdatel'stvo "Nauka" (Publishing House "Nauka"), Moscow 1965.

G.V. Jacks, R.Tavernier and D.H.Boalch: Multilingual Vocabulary of Soil Science. 430 pp., Land and Water Development Division, Food and Agriculture Organization of the United Nations, Rome 1960.

A.B. Lokhovic: Russko-nemeckij slovar' (Russian-German Dictionary). 4th edition, 919 pp., Gosudarstvennoe izdatel'stvo inostrannykh i nacional'nykh slovarej (State Publishing House for Foreign and National Dictionaries), Moscow 1960.

G.Obrejanu, I.Trifu, B.Slusanski und A.Boico: Soil Science Dictionary. English-French-German-Rumanian-Russian. 691 pp., Organizing Committee of the VIIIth International Congress of Soil Science, Bucharest 1964.

T.A. Sofiano: Russko-anglijskij geologicheskij slovar' (Russian-English Geological Dictionary). 559 pp., the same publisher as for Davydov, Moscow 1960.

In addition, we consulted the plant indices available in German and English translations of books by L.S. Berg.*) A subject index providing Russian equivalents and, in the case of botanical terms, Latin equivalents is given at the end of this

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* L.S. Berg: Die geographischen Zonen der Sowjetunion. Vols.I and II, 437 + 604 pp., B.G.Teubner Verlagsgesellschaft, Leipzig 1958/59, and L.S. Berg: Natural Regions of the USSR. 436 pp., The Macmillan Co., New York 1950.

report. In some cases the plant species investigated were not defined clearly in the Russian literature. It may be assumed, however, that whenever spruce, pine or birch is mentioned, Norway spruce, Scotch pine and European white birch is meant, respectively.

For locational and general geographical references we employed the "Atlas SSSR" (185 p.), published by the Main Administration for Geodesy and Cartography (GUGK), Moscow, in 1962.

The spectral reflectance data available to us were always in the form of diagrams, never in the form of tables. These diagrams were evaluated as precisely as possible by reading off spectral reflectance values by means of a proportional divider. The data reproduced in this report do not, therefore, reflect the accuracy of the original measurements. The data were punched on IBM cards and a program was written for the IBM 1620 machine of the Computation Center at the University of Zurich which permitted the generation of spectral reflectance plots with a maximum of three curves per plot and the tabulation of corresponding numerical values and legends. The reflectance curves, being produced by a high-speed printer, have, of course, a step-like appearance; their main function is to show major differences between curves, and more exact values can be obtained from the tables. The plots are semi-logarithmic so that equal intervals on the ordinate represent equal contrasts.

The main parts of this report are the following: A. Text with photos and diagrams reproduced directly from the Russian papers; B. Collection of computer-generated diagrams and tables; C. Bibliography, compiled on and printed out from punch cards; D. Subject index.

It should be noted that the term "reflectance" has been used throughout this report, although "luminance" or, in the case of infrared radiation, "radiance" ("luminance factor" and "radiance factor" when expressed as a percentage or fraction of 1) might have been more correct from a photometric point of view in most cases.*) It is however, in accordance with the practice mostly followed in literature oriented toward photo interpretation.

We are indebted to Mr. R. Jenefsky, Zurich, who read and corrected the English version of the manuscript an to Dr. G. Hildebrandt, Institut für Forsteinrichtung und forstliche Betriebswirtschaft der Universität, Freiburg i/B. who provided an explanation for the Russian term "polnota" (see Annotation 10). The financial support provided by the US Army, European Research Office, for this project is gratefully acknowledged.

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* Exact definitions are the following:
Reflectance: $r = F_r / F_o$, whereby F_o = incident radiation flux, F_r

TRANSLITERATION TABLE

For the transliteration of the Cyrillic characters we designed an own system which does not need any special signs and is a combination of the systems proposed by the Library of Congress and by H.H. Bielfeldt in his dictionary (see introduction). It is fully reversible with the exception of "е" and "э", which both are transliterated to "e". For use on the key punch, which does not have apostrophes, these were replaced by commas.

Cyrillic characters	Transliteration	Cyrillic characters	Transliteration
а	a	р	r
б	b	с	s
в	v	т	t
г	g	у	u
д	d	ф	f
е	e	х	kh
ж	zh	ц	c
з	z	ч	ch
и	i	ш	sh
й	j	щ	shch
к	k	ъ	''
л	l	ы	y
м	m	ь	'
н	n	э	e
о	o	ю	ju
п	p	я	ja

---

total radiation flux reflected in all possible directions. Luminance or radiance factor: $r_{\varepsilon} = B_{t\varepsilon} / B_{s\varepsilon}$. Here $B_{t\varepsilon}$ is the luminance or radiance of the test surface in direction ε, $B_{s\varepsilon}$ that of a standard surface ("perfect" diffuser).

1. Technology and methodology of spectal reflectance measurements

E.L.Krinov, in his book on the spectral reflectance of natural formations (KRINEI47SOS; English translation KRINEI53SRP), has given a description of the instrumentation used for carrying out the measurements until 1947. In the following, we shall review the most important instruments and the methods used after this time. A part of this information can also be found in M.A.Romanova's study of the spectral luminance of sand deposits (ROMAMA620TS; English translation ROMAMA64ASS).

1.1 Standard surfaces

In order to scale the reflectance measurements, i.e. to calculate percentage reflectances or reflection coefficients, one has to compare all observations with the remission from a standard surface (Russ.: "etalon") with known properties. Ideally, such a standard surface should have the following properties:

1. Complete (100 %) reflectivity;
2. Orthotropy, i.e. the radiation should be scattered uniformly in all directions, so that the brightness of the standard remains equal for all possible angles of illumination and observation;
3. Spectral neutrality, i.e. reflectance should be equal for all wavelengths.

Coatings of magnesium oxide (MgO) are closest to the ideal but their production is relatively difficult and the surface is very soon soiled under field conditions. It has been found that layers of barium sulfate ($BaSO_4$) on thick white paper as a backing are more suitable for field work, although their characteristics deviate more from the ideal than those of MgO. Barium sulfate has a reflectance of only 85 - 90 % and it lacks orthotropical properties at high oblique angles of illumination (see remarks in section 3.1.9 and annotation 1). On the other hand, it has a good spectral neutrality throughout the whole visible and near infrared spectrum (see Fig. 1). For most investigations of spectral reflectance carried out in the last few years, barium sulfate on paper, usually called "barite paper", has been used with quite satisfactory results, especially for field ground work.

For spectral surveys from the air it is somewhat difficult to measure the standard surface during the flight. To overcome this problem a special

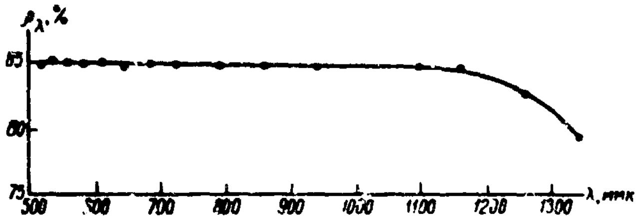


Fig. 1 Spectral reflectance of barite paper (thick white paper with a coating of $BaSO_4$) (after L. B. Krasil'chikov, from ROMAMA620TS).

standardizing device has been constructed, which will be described in section 1.5.3.

Sources: ALEKVA60SDP, BELOIN58NFI, BELOIN59ZSJ, BELOSV59AFL, ROMAMA620TS (English translation: ROMAMA64ASS).

1.2 Visual spectrometry

Visual photometry and spectrometry are based on the visual and thus subjective comparison of two light fluxes, one coming from the sample to be investigated and one from the standard surface. As such it is, of course, limited to the visible portion of the spectrum, i.e. to the 400 - 700 mμ wavelength interval. The instrument most commonly employed for visual measurements is the so-called Universal Photometer FM. It is this instrument which will be described in the following section.

1.2.1 Universal Photometer FM

The Universal Photometer FM (Russ.: "universal'nyj fotometr") is a commercially produced instrument. Fig. 2 provides a general view of it and Fig. 3 explains the optical system. The sample to be measured lies in a special holder (12) on a stage (11), which can be lowered or raised to a suitable position. Beside the sample is the standard surface (13). The light reflected from the sample and the standard passes through objectives O_1 and O_2, lenses L_1

Fig. 2 General view of the Universal Photometer FM. The disk in the lower right corner contains a set of interference filters (from BELOSV59AFL).

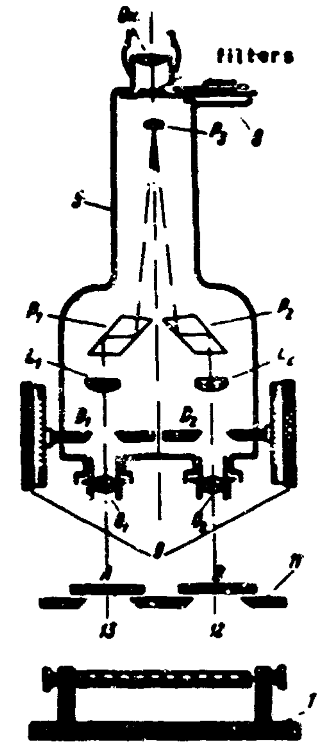


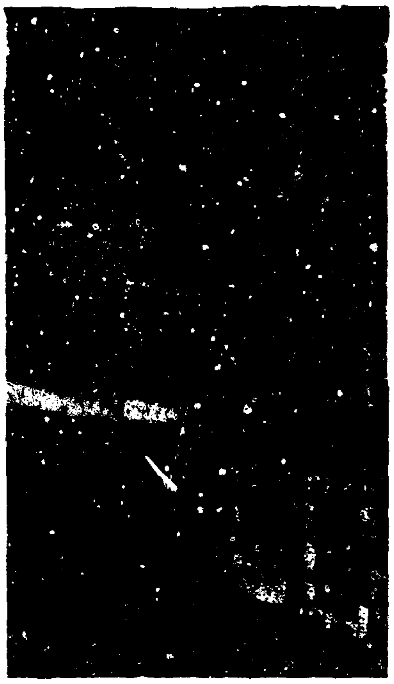
Fig. 3 Optical system of the Universal Photometer FM (from DANCVI56MIC). For explanation see text.

and L_2, prisms P_1 and P_2 and double prism P_3. The photometric field seen by the observer through the eyepiece (Ok) is divided into two halfs, one of which corresponds to the brightness of the sample, the other to the brightness of the standard. The intensity of both light fluxes can be regulated by diaphragms (D_1 and D_2) whose transmissivity is altered by turning a drum (9) and can be read off the drum in percent. For the measurement of reflectance within narrow spectral zones the instrument is equipped with a disk (8) containing a set of interference filters (see also Fig. 2). This disk is inserted between the double prism (P_3) and the eyepiece (Ok) and can be rotated for the selection of a required filter. 11 to 14 different filters are used which have transmission maxima at wavelength intervals of 20 to 30 mμ. A representative set of filters is given in Table 1.

Table 1 Representative set of interference filters used with the Universal Photometer FM (from ROMANA620TS)

No. of filter	Wavelength for transmission max. in mμ	Maximum transmission in %	Transmission width[3] in mμ
1	398	33.5	12
2	428	[illegible]5.0	14
3	447	36.0	12
4	467	33.5	12
5	479	33.0	13
6	507	24.0	12
7	518	24.0	12
8	539	28.0	13
9	565	29.0	12
10	577	20.5	11
11	593	27.0	12
12	629	28.0	14
13	641	32.5	12
14	680	22.0	12

The measurement of a sample is, in general, done in such a way the diaphragm regulating the intensitiy of the light flux from the sample is left fully open and the diaphragm over the standard is closed down until the brightnesses of the two half fields seen through the eyepiece are equal. The reflectance of the sample can be read off the drum on the sample side directly in percent of the reflectance of the standard. For measurements in the laboratory both the test and the standard surface are illuminated by a incadescent lamp under an angle of 45°. For measurements under conditions of natural illumination in the terrain or from the air the instrument has to undergo some modifications. First, the stage on the sample side is removed so that the objective can sight at the terrain underneath the photometer and second, it is either mounted on a tripod for ground work or fixed with a special holder on the outside of an airplane for airborne measurements, as shown in Fig. 4. The flight path is chosen in such a way that the sun is on the same side as the instrument and its rays cross the flight line perpendicularly (see Fig. 5).



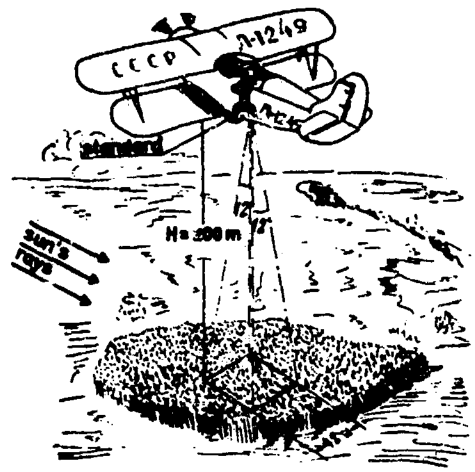


Fig. 4 The Universal Photometer FM being operated aboard an aircraft (from ARCYES580SD).

Fig. 5 Airborne measurements taken with the Universal Photometer FM (from ARCYES580SD).

Sources: ALEKVA60SDP, LJALKS60IOP, TOLCJS60PFT, ARCYES580SD, DANCVI56MIC, BELOIN59ZSJ, BELOSV57IOS, BELOSV59AFL, ROMAMA59VGI, ROMAMA62OTS (English translation: ROMAMA64ASS).

1.2.2 Areal resolution, efficiency and accuracy of measurements with the FM

The side length s of the sample area covered is given by

$$s = 2\,H \cdot \mathrm{tg}\,\beta\,, \qquad (1)$$

where H = height of the photometer lens above the sample and β = half the angular field of the photometer lens. Since the angular field 2β of the lens is 12^o, (1) can be written as

$$s = 0.21\ H \qquad (2)$$

For laboratory measurements, when the sample is on the stage at a distance of

approximately 9.5 cm from the lens, s is 2 cm and thus the area covered 4 cm^2. For ground observations in the terrain, when the instrument is mounted on a tripod, s becomes 14 cm. If the spectral surveying is done from an airplane the area covered depends on the flying height. For example, if the height is 200 m (an altitude commonly chosen for airborne measurements), s amounts to 42 m. By using objectives with longer focal lengths, also smaller areas can be measured.

The accuracy of the measurements expressed as standard deviation in a series of readings taken repeatedly at the same object is ± 3 - 5 % (percent of the measured values) for laboratory conditions, ± 4 - 7 % for field measurements and 7 - 8.5 % for observations from the air. Due to the lower sensitivity of the eye at both the blue and the red ends of the visible spectrum the accuracy is somewhat lower in these spectral regions than at intermediate wavelengths. The errors can be reduced by taking for each filter the average of three readings. The accuracy is then given by the standard error of the mean and amounts to approximately ± 1.5 - 3 % for the laboratory case, ± 2.5 - 4 % for the field case and ± 4 - 5 % for the airborne case, according to

$$s_{\bar{x}} = \frac{s_x}{\sqrt{n}} , \qquad (3)$$

where $s_{\bar{x}}$ = standard error of the mean, s_x = standard deviation of a single observation and n = number of readings.[4)]

It takes an experienced observer 5 - 8 minutes to measure one sample with all filters and about 20 minutes if each reading is repeated twice.

Sources: ALEKVA60SDP, LJALKS60IOP, TOLCJS80PFT, ARCYES580SD, DANCVI56MIC, BELOIN59ZSJ, BELOSV57IOS, BELOSV59AFL, ROMAMA59VGI, ROMAMA620OTS (English translation: ROMAMA64ASS).

1.3 Photoelectric spectrometry

In contrast to visual photometry, photoelectric radiometry is an objective method which makes use of photoelectric cells as sensors instead of the human eye. This makes it possible to extend the measurements to the near infrared spectral zone which is of interest for the air photographer or the photo interpreter who wants to draw inferences for the case of infrared photography. The photoelectric cells commonly employed are either of the barrier-layer (photo-

voltaic) or of the photomultiplier type. All cells have in common that radiation falling upon them produces a current which can be measured with an ammeter.

A variety of instruments of this type designed for either laboratory or field work are in use in the USSR.

1.3.1 Luxmeter

A simple method of photometry in the field was employed by J.S. Tolchel'nikov for an investigation of the reflectance of a number of soil types seen under various angles of observation (see section 4.1.7). He mounted a tube, which was 35 cm long, on the photocell of a luxmeter, an instrument usually used for measurements of illuminance, and this enabled him to measure the reflectance of relatively small areas from different directions. When the luxmeter was held 1 m above the surface, an area of approximately 20 cm x 20 cm was covered. The data obtained represent integral values for the entire visible portion of the spectrum and by reference to a standard reflection coefficients were calculated.

Source: TOLCJS65IRE

1.3.2 Spectrometer with a barrier-layer cell

An older model of a photoelectric spectrometer was used by A.A.Il'ina for laboratory measurements of transmission and reflection on plant leaves. The operating principle of this instrument is shown in Fig. 6. Light emanating from the filament of an incandescent lamp (Q) is projected by a lens (L_1) onto the entrance slit (S_1) of a monochromator (M). The latter contains a prism (P) as a dispersing element. The width of the entrance slit can be varied from 0.1 mm for the near infrared region to 1.0 mm for blue light. The width of the exit slit (S_2), which is 0.1 - 0.2 mm, corresponds to a spectral interval of 3 $m\mu$ in the yellow-green band. On the exit side of the monochromator interchangeable devices for measuring either transmission or reflection can be attached. In Fig. 6 only the instrumentation for the latter is shown. A spherical mirror (Sp) is mounted directly onto the exit slit. The radiation coming through the slit passes through an opening in the mirror and is centered by a lens (L_2) as a spot of 4 mm in diameter onto the sample. The radiation is reflected from the surface in a diffuse manner (rays ppp) and focussed (rays p'p'p') by the spherical mirror

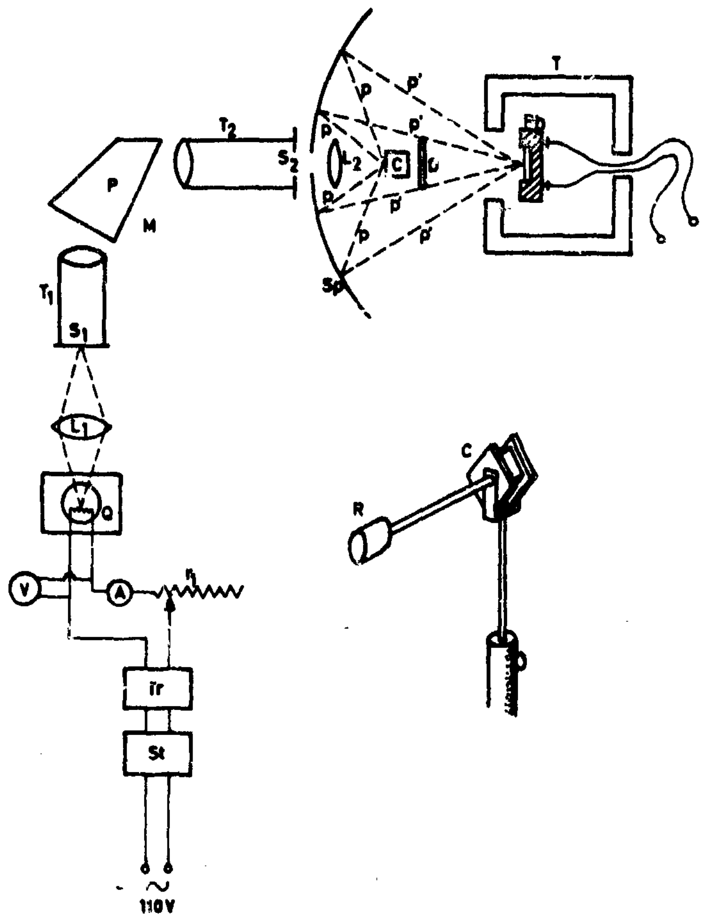


Fig. 6 Diagram of the photoelectric spectrometer with barrier-layer cell used by A. A. Il'ina for laboratory measurements of plant leaves (after ILINAA478PO).
St = stabilizer, Tr = transformer, r_1 = rheostat, controlling the intensity of lamp Q, T_1 and T_2 = monochromator tubes, D = screen, inhibiting radiation scattered from the backside of the cube to reach the photocell, T = thermostat; for further explanation see text.

onto the surface of a photoelectric barrier-layer cell (Ph). Two different cells are used: One for the visible spectral interval and one for the near infrared. The current produced is read off a microammeter. For the quick alternating

measurement of samples and the barite standard surface both are mounted on the sides of a cube (C) which can be rotated by a handle (R), as shown in the separate drawing in the lower right corner in Fig. 6.

Source: ILINAA475PO

1.3.3 Field spectrometer with photomultipliers

A spectrometer designed for field use (Russ.: "polevoj fotoelektricheskij spektrometr") within the 400 - 1000 mμ spectral region was constructed at the Laboratory of Aeromethods, Academy of Sciences of the USSR, in 1959. The apparatus works as follows: The spectral dispersion of the radiation is obtained by a diffraction grating. By rotating the grating the instrument can be set for different wavelengths. The spectral resolution is 10 mμ. A photomultiplier of the type FEU-22 (see Fig. 21) is placed in the plane of the monochromator's exit slit and receives the radiation. The photomultiplier output is amplified and displayed on a microammeter. The instrument is portable and weights about 25 kg.

For field measurements the spectrometer is put on a tripod (see Fig. 7).

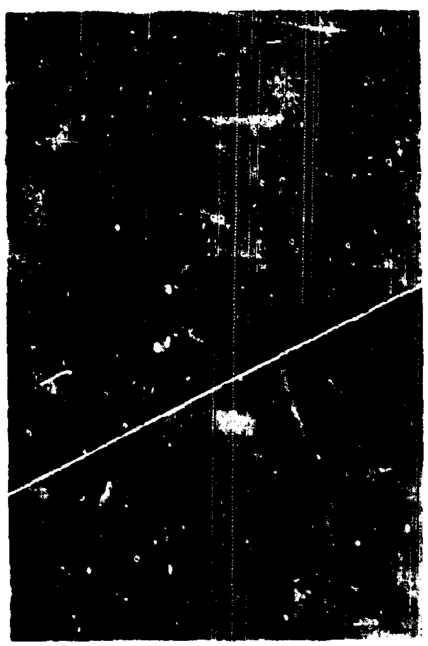


Fig. 7 General view of the photoelectric field spectrometer. The operator measures the reflectance of the standard surface (from ROMAMA62OTS).

An area of 1 m x 1 m can be measured in this position. The sensitivity of the instrument is calibrated to the reflectance of the standard so that the needle of the microammeter points to 100 divisions. The reflectance of sample surfaces can then be read off directly in percent. Measurements are usually taken at 20 mμ wavelength intervals. Two operators can measure one sample throughout the whole spectrum in 7 - 10 minutes. The accuracy obtainable is high and the standard deviation of a single reading amounts to $\pm$ 1 - 2 % (percent of the measured values).

A similar instrument, probably a predecessor of the spectrometer described above, was used by V.A. Alekseev and S.V. Belov for field recordings in 1958. It was also equipped with a photomultiplier, but its monochromator contained a prism instead of a diffraction grating.

The use of a further type of photoelectric fieldspectrometer with the designation SF-4, constructed at the Laboratory of Aeromethods, Academy of Sciences of the USSR, by Z. L. Petrushkina, has been reported by V. M. Bakhvalov. The authors of this report were not able to find out any technical details, however.[22)]

Sources: BAKHVM60MSA, ALEKVA60SDP, ROMAMA620TS (English translation: ROMAMA64ASS)

1.4 Photographic spectrometry

In photographic spectrometry film is employed as a sensor for the spectrally dispersed radiation. The film spectrograms must subsequently be evaluated with a microphotometer, which makes the photographic method of spectrometry less accurate and rather laborious. However, for airborne observations, it has the advantage over the visual method that it permits a fast recording of spectrograms. The instruments based on this principle are usually referred to as spectrographs and we shall describe commonly used types of aerial spectrographs below.

1.4.1 Aerial Spectrographs LS-2 and LS-3

The Aerial Spectrograph (Russ.: "letnyj spektrograf") LS-2 was designed by V.V.Kol'cov and N.V.Eliseeva under the direction of K.S.Ljalikov at the Laboratory of Aeromethods, Academy of Sciences of the USSR, in 1955. The LS-3 is an improved version constructed by the same institute in collaboration with the State Optical Institute in 1957. The optical system of the LS- Instruments is shown in Fig. 8. The radiation from the terrain passes through an entrance

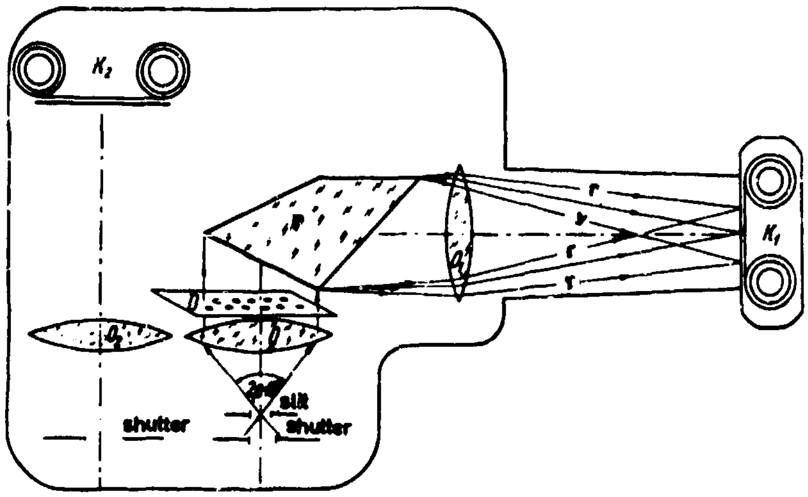


Fig. 8 Optical system of the Aerial Spectrograph LS 2 (from ARCYES580SD). r = red, v = violet; for further explanation see text.

slit of 0.15 mm width and a collimator lens (0) with a focal length of 75 mm and a relative aperture of 1:2.8. The parallel rays produced by the latter fall on a Abbé prism (P), after having been regulated in intensity by a diaphragm (D) in the form of a perforated plate. The radiation spectrally dispersed by the prism is then focussed by the lens of the spectrograph camera (0_1 with f = 248 mm, 1:6.5) onto the film plane in the spectrograph box (K_1). For the simultaneous recording of the spectrometered landscape details on ordinary air photographs a second camera (lens O_2 with f = 110 mm and 1:4.5 and film box K_2) is employed. The shutters of both cameras have an exposure range from 1 - $^1/_{250}$ second and are operated synchronously. The spectral sensitivity range of the LS-spectrographs depends on the type of film used, but, in principle, it

goes from 410 to 760 mμ for the LS-2 and from 410 to 350 mμ for the LS-3. Films commonly employed are of the panchromatic, the orthochromatic, the infrared (I-760) or the false color ("spektrozonal" SN-2) type. The spectral sensitivity of these materials is given in Fig. 9.[5]

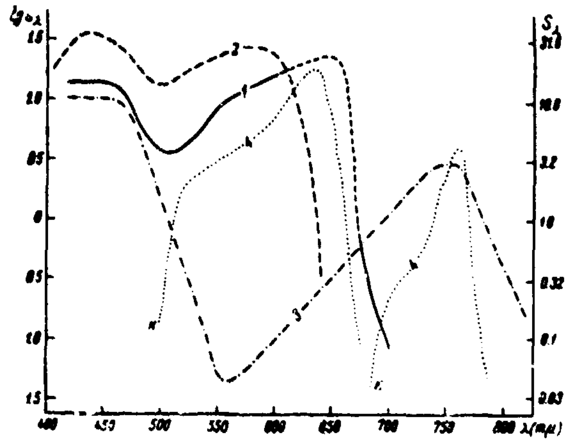


Fig. 9 Spectral sensitivity of films used with aerial spectrographs (from S.V. Belov and A.M. Berezin[6]).
1 = panchromatic (type 10-800), 2 = orthochromatic (RF-3),
3 = infrared (I-760), 4 = false color ("spectrozonal" SN-2).

Fig. 10 Set-up of the Aerial Spectrograph LS-2 on an aerial camera mount (from ARCYES580SD).
1 = circular frame, 2 = spectrograph, 3 = pivot, 4 = mechanism for tilting the inner ring of the camera mount, 5 = shock absorbers.

For measurements from the air the spectrograph is set up on an air photo camera mount as illustrated by Fig. 10. The instrument can be tilted to a maximum of 25° (LS-2) or 30° (LS-3), thus permitting the taking of low oblique observations as well. It is not possible to measure the standard needed for reference during flights. This is done on the ground immediately before take-off and after landing. For this reason, flights should not last too long. It has been found that changes in the sun's altitude of 3 - 5° do not produce any perceivable errors and thus that flight durations of 1 - 1½ hours are permissible.

The LS spectrographs can also be mounted on a tripod and employed for ground work.

Sources: ALEKVA60SDP, ARCYES58OSD, BELOSV59AFL

1.4.2 Areal resolution, efficiency and accuracy of the LS spectrographs

The area covered can be calculated from the angular field and the flying height as given in (1). The angular field 2β of the LS-2 is 18°, that of the LS-3 12°. For a flying height of 200 m the side length of the spectrometered area is thus 63 m and 42 m, respectively (see Fig. 11).

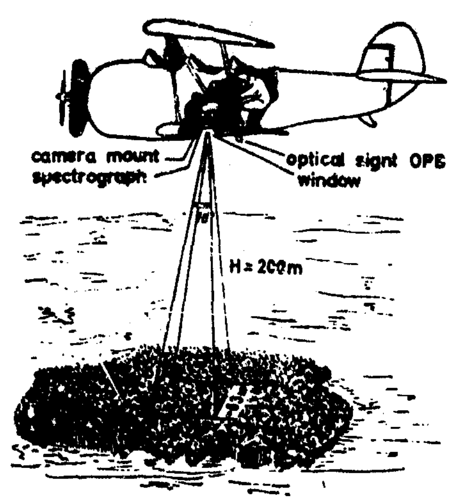


Fig. 11 Diagram showing the Aerial Spectrograph LS-2 in operational use (from (ARCYES58OSD).

These are theoretical values, however, For observations taken from an aircraft in motion the areal coverage of one recording will be somewhat larger as a result of the relatively long exposure times needed for the spectrograph camera.

A sample area can be spectrometrically surveyed with triple recordings from all directions (vertical and four oblique directions as illustrated by Fig. 12) in less than one hour.

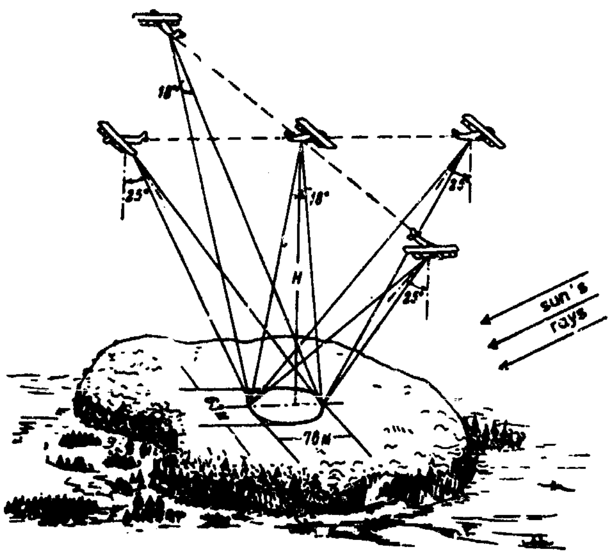


Fig. 12 Situation sketch of the surveying procedure with the Aerial Spectrograph LS-2 at nadir direction and oblique angles (from ARCYES58OSD).

Due to the relative complexity of the photographic method of spectrometry (recording of spectrograms on film and evaluation by photometer) larger errors occur than with other spectrometric instruments. The standard deviation of single recordings has been reported as ± 15 - 18 % (percent of measured values) for the 500 - 580 mμ band and as ± 10 - 12 % for the 730 mμ region. For the average of three recordings, errors reduce according to (3) to about ± 8.5 - 10.5 % and 6 - 7 %, respectively.

Sources: ALEKVA60SDP, ARCYES58OSD, BELOSV59AFL

1.4.3 Aerial Cinespectrograph RShch-1

Another type of aerial spectrograph designed at the Laboratory of Aeromethods, Academy of Sciences of the USSR, in 1957 is known as Aerial Cinespectrograph (Russ.: "letnyj kinospektrograf") RShch-1. Its optical part was constructed by J.P.Shchepetkin of the State Optical Institute. Similar to the LS-spectrographs, the RShch-1 works with two optical systems, one for spectrography and one for air photography. The difference is that a movie camera is used and that both systems are focussed onto the same film frame (16 mm x 32 mm).

The working principle of the two systems is explained by Fig. 13. There,

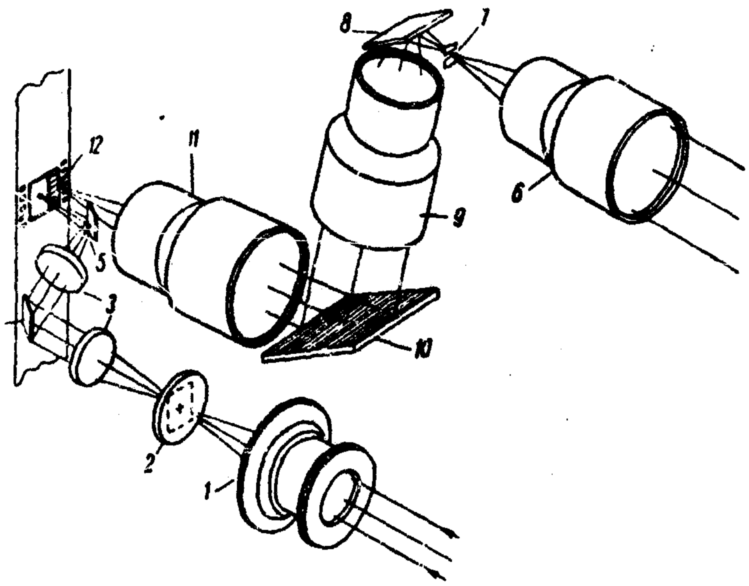


Fig. 13 Optical system of the Aerial Cinespectrograph RShch-1 (from ROMAMA60SLK). For explanation see text.

parts 1 - 5 constitute the photographic system. 1 is the object lens (Industar 22 with f = 51.4 mm and 1:3.5) and 2 a collector consisting of two planoconvex lenses. These lenses enclose a square diaphragm, which delimits the image of the terrain, and a cross-wire marking the center of the area covered. 3 to 5 is a turning system which directs the image onto the film (12) and comprising

two lenses (f=51 mm) and a mirror. The spectrographic system consists of the following elements: Three lenses (type Jupiter 9 with f = 85 mm, a relative aperture of 1:2 and an angular field of 28°) acting as condensers and collimator, respectively, an entrance slit (7), a plane mirror (8) and a reflecting diffraction grating of the echelette type with 600 lines per mm. The terrain photograph occupies two thirds (15 mm x 15 mm) and the spectrogram one third (6 mm x 15 mm) of one frame as illustrated by Fig. 14. A general view of the RShch-1 is provided by Fig. 15. Its total weight is only 6 kg. The spectral sensitivity of

Fig. 14 A representative frame exposed with the Aerial Cinespectrograph RShch-1. The upper part is occupied by the terrain photo, the lower by the spectrogram (from ROMAMA62OTS).

this instrument runs from 496 to 662 mμ, i.e., it can be used for work within the visible spectral range only. Another drawback is that, as in the case of the LS-spectrographs, the photometry of the standard can be carried out only before and after flights (see section 1.4.1).

Fig. 15 General view of the Aerial Cinespectrograph RShch-1 (from ROMAMA60SLK).
a = spectral system, b = air photographic system,
c = movie camera (type AKS-1).

Sources: ROMAMA60SLK, ROMAMA60OAS, ROMAMA62OTS, (English translation: ROMAMA64ASS).

1.4.4 Areal resolution and accuracy of the RShch-1

The spectrometer slit of the RShch-1 has a length of 6 mm and it can be set for varying widths between 0.04 and 3 mm. Its orientation is at a right angle to the direction of flight. Consequently, the size of the spectrometered area can be determined in the following way (compare with Fig. 16):

The side perpendicular to the flight direction (M) is given by

$$M = L \cdot \frac{H}{f_K}, \qquad (4)$$

where L = length of spectrograph slit, H = flying height and f_K = focal length of the spectrograph's condenser lens. Since L = 6 mm and f_K = 85 mm

$$M = 0.07\ H\ . \qquad (5)$$

The side of the spectrometered area parallel to the flight line (K) depends, in addition to the slit dimension, the flying height and condenser focal length as above, on the flying speed (v) and the exposure time for one spectrogram (t).

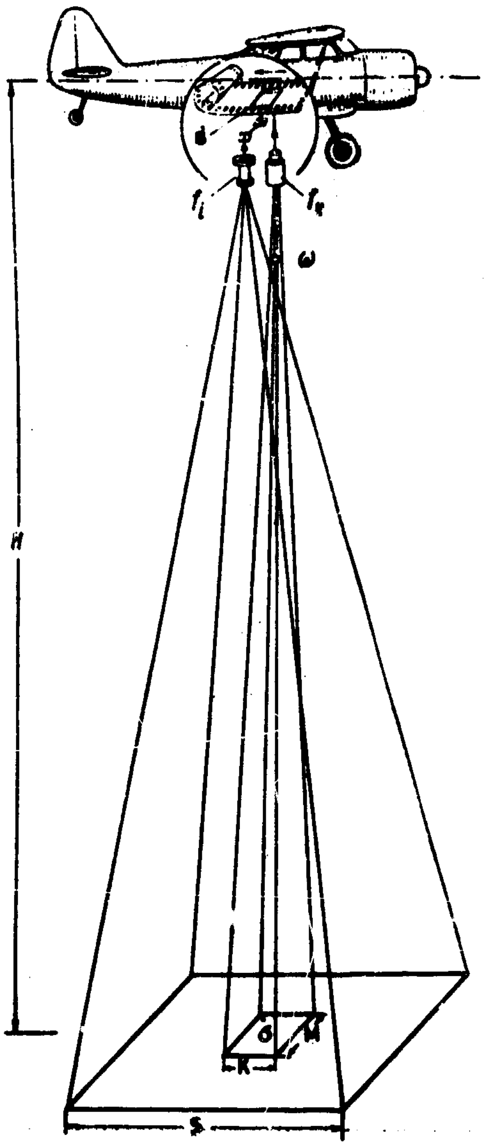


Fig. 16 Areal coverage obtained with the Aerial Cinespectrograph RShch-1 (from ROMAMA00OAS). f_l = object lens of the air photographic system, f_K = object lens of the spectrographic system; for further explanation see text.

This latter is about $\frac{1}{2n}$, where n = frequency of recordings per second.

$$K = v \cdot t + W \cdot \frac{H}{f_K}, \qquad (6)$$

where W = width of the spectrograph slit.

The side length S of the terrain section covered by the aerial photograph taken simultaneously is

$$S = \frac{H \cdot s}{f_l}, \qquad (7)$$

where H = flying height, s = side length of terrain image on the film and f_l = focal length of the aerial photographic lens. Since s = 15 mm and f_l = 51.4 mm

$$S = 0.29\ H \qquad (8)$$

Some representative values for the areal coverage at various flying heights, assuming an aircraft speed of 120 km/h, a spectrograph slit width of 0.193 mm and exposure frequency of 16 frames/sec., are given in Table 2. It is also possible to conduct spectrographic recordings without the condenser lens. In this case the dimensions of the surveyed terrain section can be derived approximately from the relative aperture of the collimator lens, which is [illegible]. Consequently, we have to use H/2 instead of H/f_K in formulas (4) and (6).

The reproducibility of results obtained with the RShch-1 was tested by M.A.Romanova and J.P.Shchepetkin

Table 2 Representative values for the areal coverage with the Aerial Cinespectrograph RShch-1 (from ROMAMA62OTS)

Flying height in m	Side length of the photographed area in m	Dimensions of the spectrometered area (compare with Fig. 16) in m	
		M	K
10	2.9	0.71	1.06
20	5.9	1.41	1.09
100	29.2	7.06	1.28
1000	291.8	70.59	3.39

over sand areas of the Sulak River delta. Fig. 17 shows three spectral curves obtained for recordings repeated over the same object. As can be seen the shape of curves remains about the same but there is a variation in their height on the ordinate. The diagram suggests that the standard deviation would be of the order of ± 10- 15 % (percent of the measured values), although elsewhere (ROMAMA62OTS, English translation: ROMAMA64ASS) it is reported that it usually does not exceed ± 5 %.

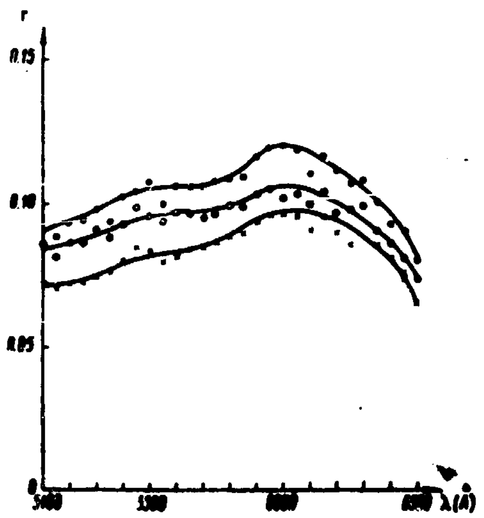


Fig. 17 Comparison of spectral reflectance curves obtained by recording spectrograms over the same object repeatedly to test the reproducibility of measurements with the Aerial Cinespectrograph RShch-1 (from ROMAMA60SLK).

Sources: ROMAMA60SLK, ROMAMA60OAS, ROMAMA62OTS, (English translation: ROMAMA64ASS).

1.4.5 Processing of spectrograms

In order to calculate percentage reflectance from film spectrograms, one needs a densitometric calibration which is obtained by recording a standard surface. However, since contrasts may be altered by the processing of the film, this is repeated several times with varying exposure, i.e. light reflected from the standard is weakened stepwise by introducing a set of neutral filters with different transmissivities, or a step wedge as in the case of the RShch-1, or a set of diaphragms in the form of perforated plates (D in Fig. 8) as in the case of the LS-spectrographs (compare with Table 3).

Table 3 Set of diaphragms used in the Aerial Spectrographs LS-2 and LS-3 to produce sensitometric control for the film spectrograms (from BELOSV59AFL)

No. of diaphragm	Transmissivity in %
0	100
1	70
2	61
3	53
4	42
5	30
6	17
7	7
8	3

This procedure produces a number of different film densities from which characteristic film curves can be constructed. Moreover, film density is not only a function of exposure but also of wavelength and, consequently, such curves have to be determined for all important wavelengths as illustrated by the example in Fig. 18.

The densities of the film spectrograms are measured with a microphotometer. An instrument commonly used for this purpose is the MF-2 (see Fig. 19). It permits the measurement of spots as small as 0.2 mm in diameter. Readings are taken at 10 to 20 mμ intervals. More recently, a recording microphotometer (microdensitometer), called MF-4, has come into use. The spectral calibration of the spectrograms is accomplished by recording the emission spectra of argon, mercury or iron with known emission lines.

Sources: BELOSV59AFL, ARCYES58OSD, ROMAMA62OTS (English translation: ROMAMA64ASS), BELOSV57IOS.

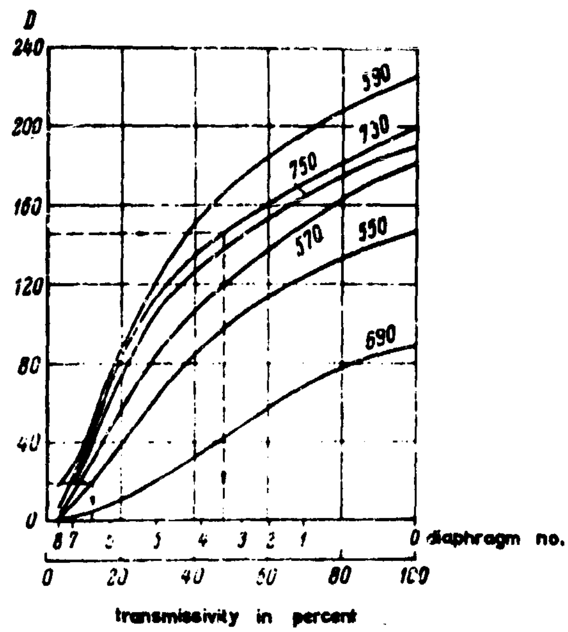


Fig. 18 A family of characteristic film curves determined by exposing film in the aerial spectrographs of the LS type to the light reflected from a standard surface (barite plate) at different wavelengths. The exposure (abscissa) is varied by means of a set of diaphragms with different transmissivities (compare with Table 3). The ordinate values are film densities (from BELOSV59AFL).

Fig. 19 The Microphotometer MF-2 used for the evaluation of spectrograms obtained with aerial spectrographs (from BELOSV59AFL).

1.5 Photoelectronic spectrometry

The method of spectrometry referred to here as "photoelectronic" makes use of photomultiplier cells as is the case with field spectrometers, but their output is displayed as continuous spectral curves on the screen of a cathode ray tube (oscillograph). This screen is photographed at regular intervals. This is the latest development in the field of spectrometry, and in the course of the last 10 years a whole family of instruments of this type, usually known as "Spectrovisors", has been constructed for airborne use in the USSR. Their main advantages are the higher sensitivity and the higher rate of recording which permits a spectral survey of smaller areas than with other instruments.

1.5.1 Aerial Cathode Ray Spectrometers (Spectrovisor) of the S-type

One of the early instruments using the photoelectronic principle of spectrometry was the Spectrovisor (Russ.: "spektrovizor") S-2 constructed by V.V.Kol'cov during the years 1954 - 57 at the Laboratory of Aeromethods, Academy of Sciences. Its working principles are explained by Fig. 20.

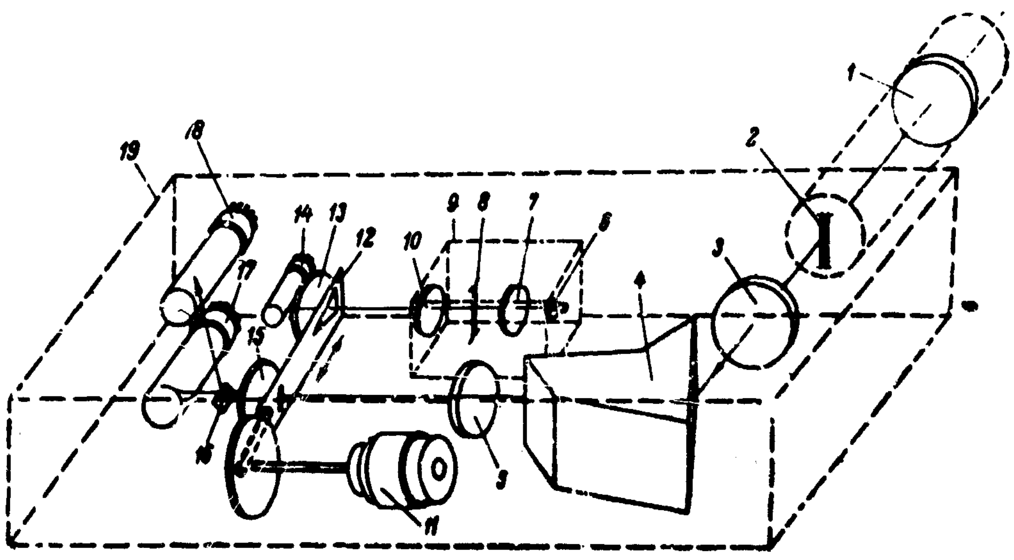


Fig. 20 Optical system of the Spectrovisor S-2 (from KOLCVV59PSI). For explanation see text.

The radiation reflected from the terrain passes through a condenser lens (1) (f = 210 mm, 1:4), the entrance slit of the monochromator (2), a collimator lens (3) (f = 110 mm) and is spectrally dispersed by a prism (4). A further lens (5) (f = 280 mm) focusses the spectrum onto the plane of the exit slit and from there the radiation flux is transmitted by a collector lens (15) and a semi-transparent mirror (16) to the photocathodes of two photomultipliers (17 and 18). These are of the type FEU-17 (antimony-cesium cathode) and FEU-22 (cesium oxide - silver cathode), respectively, and are different in spectral sensitivity (see Fig. 21) so that the instrument has a wide spectral working range from

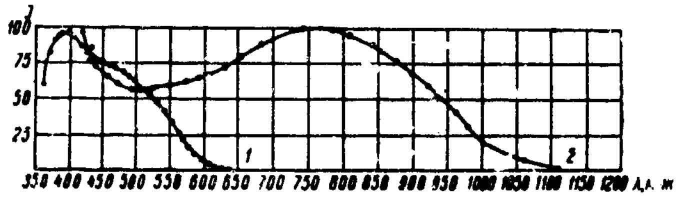


Fig. 21 Spectral sensitivity of photomultipliers commonly used with photo-electric and cathode ray spectrometers (from ROMAMA62OTS).
1 = FEU-17, 2 = FEU-22.

400 - 1000 mμ. The exit slit of the monochromator is cut into a templet, which, driven by an electric motor (11), moves back and forth and provides for spectral scanning. The same movement is utilized to generate the horizontal sweep needed on the cathode ray tube. This is achieved in the following way: Light from a incandescent lamp (6) is transmitted by two lenses (7 and 10) and a narrow slit (8) to a triangular opening (12) in the templet. The flux passing through is collected by a lens (13) and activates a photomultiplier (type FEU-20) (14). The intensity of the signal produced depends on the position of the triangle. After amplification it is employed to generate horizontal deflection of the cathode ray tube beam synchronously to the spectral scanning. Likewise, the amplified voltages from the photomultipliers FEU-17 and FEU-22 produce a deflection in the vertical direction which is proportional to the spectral intensity of the radiation received. Spectral curves are displayed on the cathode ray tube during the templet's movement in one direction only. During the reverse travel a zero line is shown. The two photomultipliers can be switched on and off independently of each other so that it is possible to use only one of the two for specific purposes.

A movie camera (type KS-50-B) is attached to the spectrometer and photographs the terrain. An identical camera, synchronized with the first one, records the oscillograms appearing on the cathode ray tube. For the identification of corresponding frames produced by the two cameras, small lamps are placed within the angular field of both and switched on at every eighth frame. As a result, marginal light marks appear on the films. The whole set-up aboard the plane is shown in Fig. 22. Fig. 23 provides an example for the material ob-

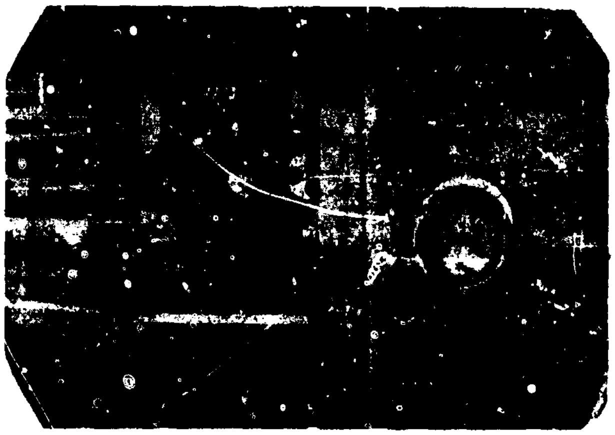


Fig. 22 Set-up of the Aerial Cathode Ray Spectrometer (Spectrovisor) S-2 aboard the plane, seen from below. At left is the movie camera which photographs the terrain, at right the spectrometer with the object lens (from KOLCVV59PS).

tained with the S-2.

The orientation of the two cameras relative to each other is determined as follows: Two terrain surfaces with a high contrast and a straight line boundary between them, such as a road and surrounding fields or the sea and the shore, are selected. Two runs are conducted with the aircraft, one with normal orientation of the spectrometer and one with the instrument rotated 90° around its optical axis. As a result, the straight line boundaries appearing on the two air photo film strips intersect each other at a right angle. The contrast between the two surfaces will produce a sharp change in signal intensity on the cathode ray tube and by selecting the corresponding terrain photos the exact position of the spectrometered area within the air photo frame can be determined from the point of intersection of the straight line boundaries.

A whole series of further Aerial Cathode Ray Spectrometers, each with some improvements and called spectrovisors S-3, S-4, etc. was subsequently constructed by V.V.Kol'cov (for a detailed account see KOLCVV63ASI). For

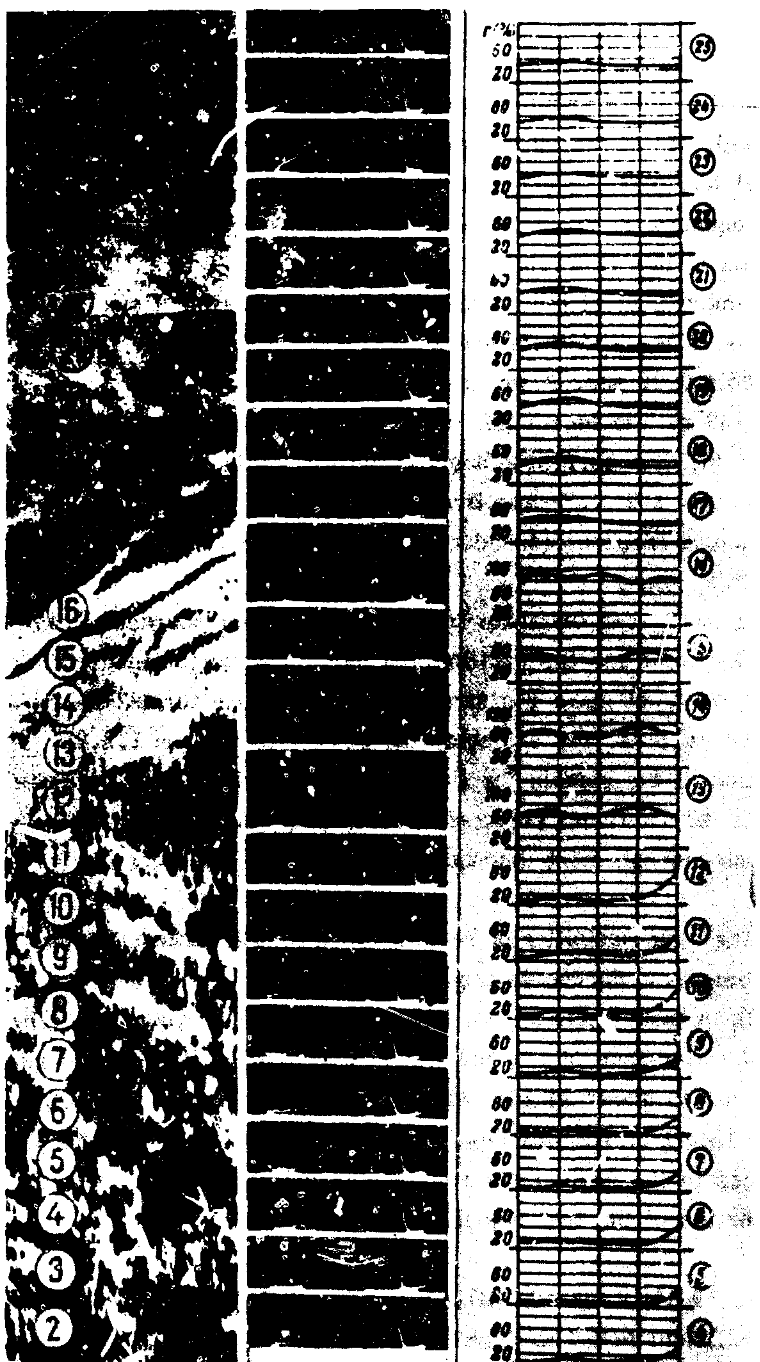


Fig. 23
Example for the film recordings obtained with the Aerial Cathode Ray Spectrometer (Spectrovisor) S-2. On the left side is the surveyed terrain strip as photographed by the movie camera (mosaicked together from individual frames), in the middle a series of corresponding oscillograms. The calculated spectral reflectance curves (see section 1.5.5) are on the right side (from KOLCVV59PSI).

example, the S-3, produced in 1957, uses a vibrating mirror instead of the moving slit for wavelength scanning. This instrument was employed primarily in experiments of sea depth determination from spectral returns. Since for this purpose the 545 - 555 mμ interval is most important, the instrument is equipped with a antimonium - cesium photomultiplier with maximum sensitivity in the blue-green spectral band (see JANUDA61ISO).

Sources: JANUDA61ISO, KOLCVV63ASI, KOLCVV59PSI, ROMAMA62OTS
(English translation: ROMAMA64ASS).

1.5.2 Areal resolution and accuracy of the S-2 Spectrovisor

The dimensions of the spectrometered terrain section can be determined in the same way as for the RShch-1 spectrograph, i.e., from formulas (4) and (6). Length (L) and width (W) of the spectrometer slit are 3 mm and 0.3 mm, respectively. The focal length of the condenser lens is 210 mm. Measurements can be taken with a frequency of 20 cps so that the time needed for one measurement is 0.05 sec. Much of this time, however, is used up by idle running, i.e. especially by the back movement of the scanning device. The actual time (t) during which the intensities of one spectrum are shown on the cathode ray tube and recorded on film is about 0.01 sec. If we assume a flying speed of 160 km/h and a flying height of 150 m the length (M) of the surveyed area is about 2 m, the width (K) about 0.6 m. The corresponding figures for a flight altitude of 1000 m are about 14 m and 1.8 m, respectively. Later spectrovisors of the S family have higher scanning frequencies and an improved ratio between the idle running and actual working time.

Errors in measurement can originate from three different sources: From the optical, the photoelectrical and the oscillograph part. The combined error introduced by the first two is of about the same order as the one for photoelectrical spectrometers such as, for example, the SF-4 (see section 1.3.2). Through the amplification of the signals for the cathode ray tube and the evaluation of the oscillograms an additional error of about ± 2 % occurs. The total standard deviation of one measurement amounts to about ± 3 % (percent of measured values).

To investigate the reproducibility of results obtained with different types of spectrometric instruments comparative tests were carried out with a visual photometer (type UF-2), a photoelectric field spectrometer and a spectrovisor by measuring the spectral reflectance of colored paper in relation to a barite standard. An example of the results is shown in Fig. 24. All curves are similar in shape, but differ somewhat in height on the ordinate. A probable explanation for this incongruity are differences in the angular field of the three instruments and the non-orthotropical properties of the test object.

Sources: JANUDA61ISO, KOLCVV63ASI, KOLCVV59PSI, ROMAMA62OTS
(English translation: ROMAMA64ASS).

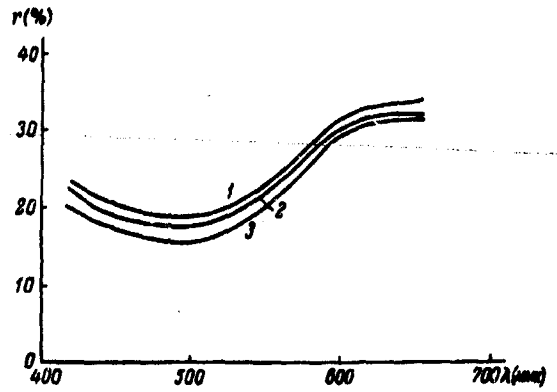


Fig. 24
Comparative spectral reflectance curves of colored paper obtained with a photoelectric field spectrometer (1), a spectrovisor (2) and a universal photometer (3) (from KOLCVV59PSI).

1.5.3 Model 1959 Spectrovisor

Another aerial cathode ray spectrometer, known as the "Model 1959 Spectrovisor, (Russ.: "spektrovizor obrazca 1959 g."), was constructed at the Laboratory of Aeromethods, Academy of Sciences, by a group of scientists headed by K.E.Meleshko. Fig. 25 shows its optical system in diagrammatic form. The working principles are similar to those of the S-2, except for the dispersing element and the wavelength scanning device, which are a diffraction grating with 600 lines per mm (4) and a vibrating mirror (5), respectively. With the mirror principle higher scanning frequencies can be obtained. System 14 to 20 provides for the formation of two marks indicating the boundaries of the spectrum on the cathode ray tube. System 21 to 26 is employed to calibrate the instrument with the flux transmitted by a glass filter (type PS-7) (25) with characteristic absorption bands. A Dove prism (26) opens and closes the entrance slit (2) of the spectrometer to radiation coming from the object lens (1). In the closed position, the slit transmits filtered radiation from a lamp (21). Element 27 is a shutter used for marking the zero intensity on the cathode ray tube. The spectral resolution of the instrument is 20 mμ.

As in the case of the S-2, a movie camera (type KS-50) films the screen of the cathode ray tube. However, the same camera also photographs the terrain through a specially mounted additional lens. An example of a frame produced by this camera is shown in Fig. 26. Measurements are made with a frequency of 12 - 32 frames per second. A general view of the spectrometer is given in Fig. 27.

A special feature of this spectrovisor is a device permitting an intensity calibration of oscillograms at regular intervals during the flight. Previously,

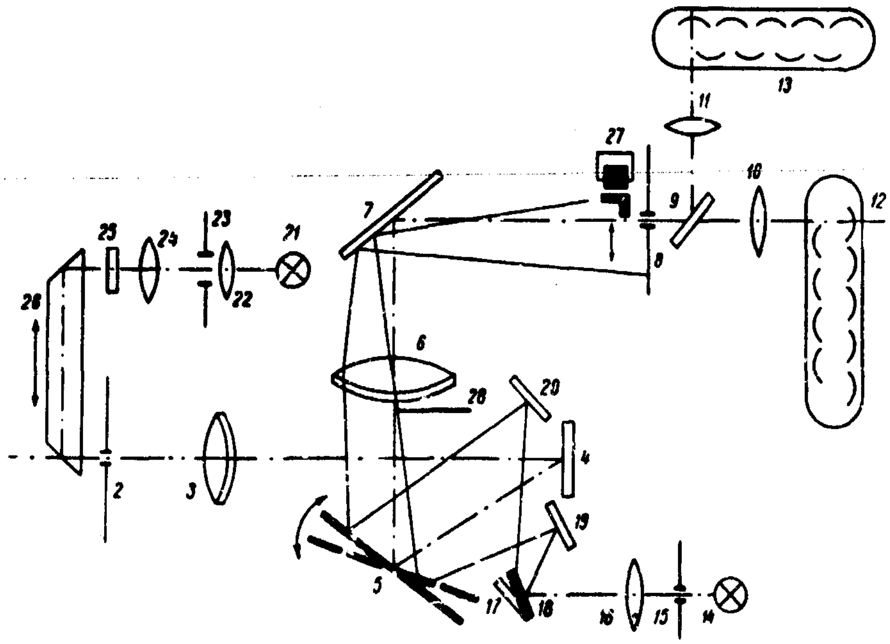


Fig. 25 Optical system of the Model 1959 Spectrovisor, constructed by K.E. Meleshko et al. (from ROMAMA62CTS).
1 = object lens, 2 = entrance slit, 3 = collimator lens, 4 = diffraction grating, 5 = vibrating mirror, 6 = magnifying lens, 7 = mirror, 8 = exit slit, 9 = semi-transparent mirror, 10 and 11 = lenses, 12 and 13 = photomultipliers (types FEU-17 and FEU-22, compare with Fig. 21), 14 = incandescent lamp, 15 = diaphragm, 16 = lens, 17-20 = mirrors, 21 = incandescent lamp, 22 = lens, 23 = diaphragm, 24 = lens, 25 = filter, 26 = Dove prism, 27 = shutter.

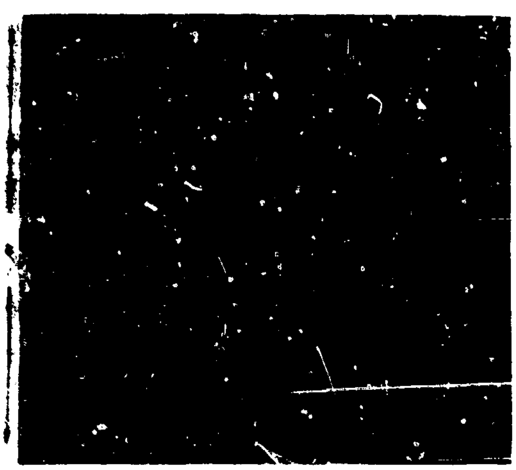


Fig. 26
Example of a frame produced by the movie camera of the Model 1959 Spectrovisor. On the left side is the terrain photo, on the right side the oscillogram photographed from the cathode ray tube. The small area a x b represents the terrain section covered by the angular field of the spectrometer (from ROMAMA62OTS).

Fig. 27
General view of the Model 1959 Spectrovisor (from VORONM60USI).
1 = cathode ray tube, 2 = amplifiers and sweep generator, 3 = movie camera, 4 = air photographic object lens, 5 = spectrometer lens, 6 = monochromator.

a calibration could be conducted only before and after flight. The spectrometer is fastened in the door opening just outside the plane in such a way that it can be rotated around a horizontal axis. In the normal position it points downward and surveys the terrain. For calibration it is turned upward and fitted into a tube with a dull white paint on the inner surface and carrying a flat piece of frosted glass (see Fig. 28). The radiation coming from the sun and the sky is

Fig. 28
Mounting of the Model 1959 Spectrovisor outside the aircraft. The spectrometer (S) is shown in upward position to measure the radiation falling through the standardizing device (D) (from ROMAMA62OTS).

diffused by this device and recorded by the spectrometer as reference (see Fig. 28). Such an in-flight calibration requires 1 to 2 sec. By repeating this procedure several times during a flight, changes in illumination can be observed and taken into account. The recordings of this standardizing device have a known relationship to the reflectance of a barite standard, i.e. the tube has been calibrated on the ground under various conditions of illumination to a normal standard surface.

The overall accuracy of the Model 1959 Spectrovisor, expressed as standard deviation, is $\pm$ 2 - 3 % under laboratory conditions. For operational airborne use the error is somewhat greater, especially in the infrared region. The main drawbacks of this spectrometer are its great weight (110 kg), the moving parts (scanning mirror), which are easily damaged, the relatively thick curves produced on the cathode ray tube and navigational difficulties during flights due to the off-axis position of the assembly.

Sources: ROMAMA62OTS (English translation: ROMAMA64ASS), VORONM60SIP + VORONM60SIS (English translation: VORONM60USI)

1.5.4 Aerial Interference Spectrometer LIS-2

Another solution for wavelength scanning was chosen for the Aerial Interference Spectrometer (Russ.: "letnyj interferencionnyj spektrometr") LIS-2, developed at the Laboratory of Aeromethods, Moscow State University. It is equipped with a set of interference filters mounted on a rotating disk. This makes the construction much simpler and less sensitive to mechanical shocks. The disk performs about 20 revolutions per sec. and can carry up to 43 different filters. The filters have a diameter of 16 mm, their spectral half width[2)] is 10 mμ and their maximum transmission varies between 20 and 50 %. Otherwise, the construction is similar to that of other spectrovisors, i.e., radiation is sensed by a photomultiplier, the output is amplified and fed into a cathode ray tube. However, only one photomultiplier of the type FEU-22 is used, which gives the instrument a spectral sensitivity range from 370 to 1000 mμ and maximum sensitivity in the 750 $\pm$ 1000 mμ band (see Fig. 21). Of this only the interval between 400 and 900 mμ is utilized, however. The constructional simplifications cut the weight of this spectrovisor down to only 30 kg. The side length of the area covered is about $^1/_{50}$ of the flying height. In contrast to the Model 1959 Spectrovisor (see 1.5.3) no means is provided for intensity calibra-

Fig. 29 General view of the Aerial Interference Spectrometer LIS-2. The movie camera photographing the oscillograph screen has been removed (from RASPNA64ISI).

tion during flight, so that the standard surface (barite paper) has to be measured before and after missions. The standard deviation of single recordings is ± 2 - 3 %.

A general view of the LIS-2 is given by Fig. 29. One should note that in this illustration the movie camera registering the oscillograms has been removed.

Source: RASPNA64LSI.

1.5.5 Processing of oscillograms

To obtain reflectance values in percent, the oscillograms of investigated objects are compared with a standard oscillogram. This is either a recording made of a barite paper before and after the flight or a curve measured through the standardizing device during the flight in the case of the 1959 Model Spectrovisor (see section 1.5.3). Object and standard oscillograms are traced from the film on tracing paper. Since the standard curve represents known reflectance values, the reflectance of the object can be determined for each wavelength by comparing the ordinates of its oscillogram with the standard ordinates.

Source: ROMAMA62OTS (English translation: ROMAMA64A3S).

1.5.6 Spectrozonal Computing Spectrovisor for line-scan imagery

Recent trends in the construction of aerial spectrovisors go in the direction of instruments which are not used as spectrometers in the conventional sense, but which instead produce line-scan imagery. Although this does not fall strictly under "measurement of spectral reflectance", for the reader interested we present here one example, the Spectrozonal Computing Spectrovisor[7] designed by V.V. Kol'cov at the Laboratory of Aeromethods, Academy of Sciences in the early nineteen-sixties. The working principles are illustrated by Fig. 30.

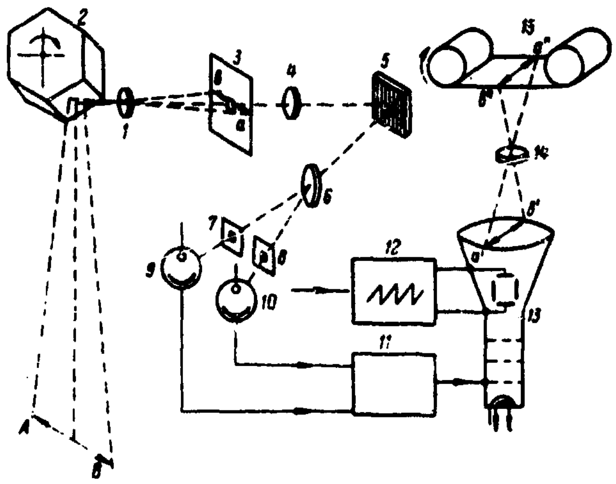


Fig. 30
Working principles of the Spectrozonal Computing Spectrovisor (from KOLCVV66SAP). For explanation see text.

Line scanning of the terrain is performed by a rotating mirror drum (2). Lens 1 projects the image onto the entrance slit (3) of a bichromator, which consists of lenses 4 and 6, a reflecting diffraction grating (5) and two exit slits (7 and 8). These exit slits can be adjusted for various wavelengths independently of each other. The radiation passing through the slits is received by two photomultipliers (9 and 10). The electric currents produced are processed in an electronic computing device (11) and the output of this latter governs the intensity of the scanning spot on a cathode ray tube (13). The generator (12) for the sweep of the spot is synchronized with the mirror drum. By means of lens 14 the line image is projected onto the film plane (15). The computer processes the signals in such a way that

$$D = f\left(\log \frac{B_{\Delta\lambda_1}}{B_{\Delta\lambda_2}}\right) ,$$

whereby D = film density and $B_{\Delta\lambda_1}$ and $B_{\Delta\lambda_2}$ = the radiation intensities at the two wavelength intervals given by the exit slits. In other words, the density of the exposed film is the result of the ratio between spectral signals received from two narrow wavelength bands. For a given purpose spectral bands can be chosen which produce different contrasts $B_{\Delta\lambda_1}/B_{\Delta\lambda_2}$ for objects to be separated. It would also be feasible to build instruments which are sensitive to more than two spectral intervals.

Source: KOLCVV66SAP.

1.6 Preparation of samples for laboratory and field measurements

1.6.1 Soil and rock samples

For the systematic investigation of reflecting properties of soil materials with a visual photometer in the laboratory the standard practice for the preparation of samples is as follows. Material is usually taken from the surface layer (depth 0 - 0.5 cm). A part of the sample is subjected to an analysis of moisture content, of chemical and granulometric properties. Another part is pulverized in an iron mortar and, in order to make material from different soils comparable, passed through a sieve with a mesh-width of 1 or 0.5 mm (sometimes also 0.1 mm) or through a set of sieves if different fractions are to be compared and brought to an air-dry state. Before drying, the samples are also purified of iron added during the work in the mortar by means of a magnet and foreign dust and smaller particles which stuck to larger ones are removed by rinsing with water and decanting. For the measurement the material is put into a tray and the surface smoothed out by means of a piece of glass.

For the analysis of the influence of moisture on reflectance, various amounts of distilled water are added to the samples by means of a pipette and the material is thoroughly mixed with a rubber pestle. To avoid the loss of water through evaporation during measurements, the tray containing the soil material is in this case covered by a plane parallel glass plate. This plate lowers the apparent reflectance of samples by 2 - 3 % (percent of measured values). This error lies within the accuracy of the method of measurement and can be neglected. The volumes of water added are either known beforehand or determined after the measurement by weighing and drying the material until no

further change in weight can be observed.

V.I. Danchev employed a similar method for the laboratory investigation of rock samples. He broke a piece of rock into small parts, ground these to powder in a mortar and than prepared the sample in the same way as described above. It should be noted, however, that reflectance from such samples may be considerably different in comparison with that from natural rock surfaces, as has been criticized by M.A. Romanova (ROMAMA62OTS, English translation: ROMAMA64ASS).

Sources: TOLCJS60PFT, TOLCJS59OTP, BELOIN58NFI, DANCVI56MIC.

1.6.2 Vegetation samples

For the measurement of the reflectance from trees on the ground by means of a visual photometer or a photoelectric field spectrometer, freshly cut branches or parts of branches are laid out in several layers on a plywood plate in such a way that the wood is entirely covered.

The spectrometering of whole tree crowns is carried out from a tower 14 - 15 m high. Sample trees are felled in the vicinity, the upper halves are cut off, put under the tower and measured within 1/2 - 1 hour after cutting (see Fig. 31).

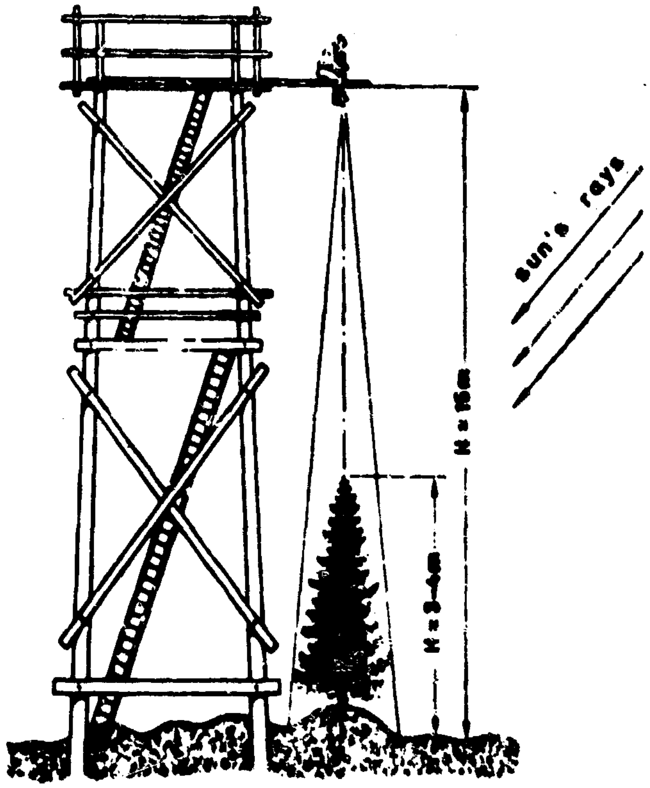


Fig. 31
Set-up for the measurement of spectral reflectance of whole tree crowns from a tower (from BELOSV59AFL).

In cases where ground measurements were carried out and no detailed description of the method of measurement is given, it has to be assumed that the spectrometric instrument was put on a tripod and that a part of the integral surface cover was recorded (for example agricultural crops and desert plants).

Source: BELOSV59AFL, ALEKVA60SDP.

2. Brief description of major projects and project areas

The following sections will provide a short description of major spectral reflectance measurement projects, including a survey of the geographical environment of project areas (see also map). In addition to the information taken directly from the Russian papers concerned, the reporters have made use of the comprehensive work by L.S.Berg on the geographical zones of the USSR[8] and, in the case of the Caspian Lowland, also of M.S.Simakova's account of soil mapping by means of color air photography[9].

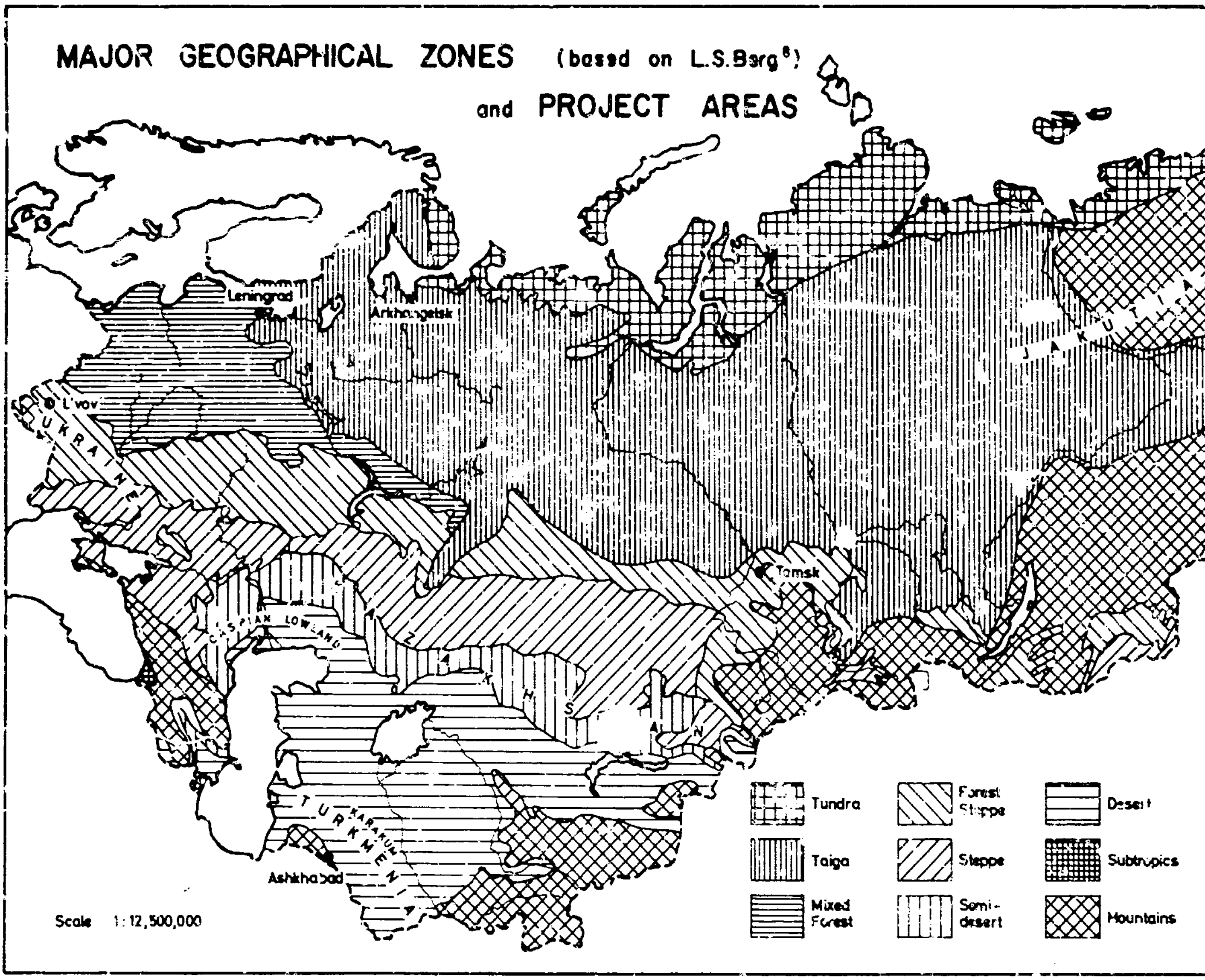
2.1 Leningrad area

From June 13 to October 2, 1955, E.S.Arcybashev, S.V.Belov and N.G.Kharin of the Laboratory of Aeromethods, Academy of Sciences of the USSR, conducted spectral reflectance measurements in the area of the experimental forest of Lisino in the "rayon" of Tosna, district ("oblast'") of Leningrad. Parallel observations on the phenology of the vegetation were taken by A.M.Beresin, V.I.Lement'ev and I.A.Trunov of the same institution.

The study area belongs to the Ladoga-Ilmen-Lowland. The underground is composed of Devonian limestones and marls and covered by quaternary deposits, among which heavy varve clays (banded clays) are of special importance as soil-forming material. The soils are, in general, weakly podzolized. The climate is characterized by a mean January temperature of about -8° C, a mean July temperature of about + 16° C and an annual precipitation of about 600 mm.

The vegetation encountered in the area is typical for the southern part of the taiga belt with Scotch pine, Norway spruce, European white birch and aspen as characteristic species. The forest stands are predominantly mixed and an average stand consists of 30 % spruce, 30 % pine, 20 % birch and 20 % aspen. Site classes II and III prevail. Table 4 provides a description of pure stands with associated soils selected for reflectance measurements.

Terrestrial measurements were carried out with the Universal Photometer FM (see section 1.2.1) at seasonal intervals on young and old shoots of spruce (see Diags. 6 - 8 and 13) and pine (Diags. 14, 56 and 57) and leaves of birch (Diags. 15, 24, 56 and 57) and aspen (Diags. 56 and 57) (for the preparation of samples see section 1.6.2). For the two coniferous species, samples


MAJOR GEOGRAPHICAL ZONES (based on L.S.Berg[8]) and PROJECT AREAS
Leningrad
Arkhangelsk
L'vov
UKRAINE
CASPIAN LOWLAND
KAZAKHSTAN
Tomsk
JAKUTIA
TURKMENIA
KARAKUM
Ashkhabad
Scale 1:12,500,000
Tundra
Taiga
Mixed Forest
Forest Steppe
Steppe
Semi-desert
Desert
Subtropics
Mountains

were obtained from trees in stands of the bilberry and wood-sorrel spruce and pine forest type with site class II - III, age class V - VI and a density[10] of 0.6 - 0.8. To some extent also the influence of site conditions on reflectance was investigated. Some comparative results are given in Diags. 14 and 15. A few recordings of the reflectance of the ground cover under the trees (herb and moss layer) were taken as well.

A LS-2 spectrograph and a Universal Photometer FM (see section 1.2.1) served for reflectance measurements from the air. Of each principal tree species, i.e. pine (Diags. 26, 58 - 60), spruce (Diag. 58), birch (Diags 35, 58 - 60) and aspen (Diags. 30, 59 - 60) a pure stand (see description in Table 4) was selected for investigation. With the FM only observations in the vertical direction could be made, whereas the LS-2 also permitted measurements at oblique angles (Diags. 26, 30, 35). Additional cover types measured from the air included forest clearings (Diag. 35), upland meadows (Diag. 62) and peat digging areas (Diag. 65).

Source: ARCYES58OSD, BELOSV57IOS, BELOSV59AFL.

2.2 Tomsk area

Another study area chosen by the Laboratory of Aeromethods, Academy of Sciences of the USSR, for the collection of reflectance data is a forest near Tegul'det in the district of Tomsk, some 200 km northeast of the city of Tomsk. The field work was carried out by S.V.Belov, E.S.Arcybshev and V.A.Alekseev between July 5 and September 15, 1957.

The area around Tomsk has a continental climate with a mean January temperature of -20° C., a mean July temperature of +18° C. and an annual rainfall of 400 mm. Although, according to L.S.Berg's map[8] of the geographical zones of the USSR, Tegul'det lies just south of the taiga belt in the forest steppe zone, the tree species occuring in the area are typical for the southern part of the taiga: Norway and Siberian spruce, Scotch and Siberian stone pine, Siberian fir, European white birch and aspen (see description of stands in Table 5).

Reflectance measurements of whole tree crowns (see section 1.6.2) were conducted for the above species with a Universal Photometer FM and partly with a spectrograph LS-3 (see sections 1.2.1 and 1.4.1, respectively) from a tower. Some results of these investigations are reproduced in the report, namely for

Table 4 Characteristics of sample plots with pure forest stands in the Leningrad area (from ARCYES580SD)

P = Scotch pine B = European white birch I = Upper story H_m = Tree height in m
S = Norway spruce A = Aspen II = Lower story D_{cm} = Diameter breast-high in cm

No. of plot	Stand composition	Age years	Site class	Density[10]	Crown closure	Forest type	H_m/D_{cm} of dominant species	Young growth(Y) Shrub layer (S)	Herb and moss layer	Soil
1	I: 10P II: 10S	120 80	III	0.78 0.22	0.7 0.1	Bilberry pine forest	24.7/24.8 15.0/16.0	Y: spruce, 45years, sparse; S: - .	Bilberry, sedges, Cassandra, peat-moss	Loamy, wet
2	I: 10S	80	II	0.83	0.8	Wood-sorrel spruce forest	23.5/27.0	Y: spruce, 30years, medium density; S: service tree, alder, sparse.	Wood-sorrel, ferns, schin-leaf, green mosses	Gravelly loam fresh
3	I: 10B II: 10S	70 50	IV-III	1.00 0.15	0.85 0.15	Sedge-highbog birch forest	17.0/14.5 9.3/10.5	Y: spruce, 30years, sparse; S: buck-thorn, sparse.	Sedges, horse-tails, peat-moss	Loamy, wet
4	I: 10A II: 10S	80 70	I	0.76 0.28	0.7 0.2	Wood-sorrel aspen forest	29.3/33.0 18.0/18.5	Y: spruce, 40years, very sparse; S: - .	Wood-sorrel, bilberry, green mosses	Loamy, fresh

Scotch pine in Diags. 11 and 53, for Siberian stone pine, Siberian fir and aspen in Diag. 44, and for Siberian spruce and European white birch in Diag. 53. For some crowns measurements were repeated for a period of one to six days in order to study how the disturbance of the metabolism would influence the reflectance. Only a few observations were made, however, and no detailed results have been reported.

Branches were collected from the same trees for a parallel investigation of the spectral reflectance of leaves and needles by means of the FM (for the preparation of samples see section 1.6.2). Examples are given for Scotch pine in Diag. 11 and for aspen in Diag. 19. In some instances also fresh branches without leaves and needles (see Diag. 31) and

Table 5 Characteristics of sample plots with pure forest stands in the Tomsk area (from BELOSV59APL)

A = Aspen F = Siberian fir Ps = Siberian stone pine H_m = Tree height in m
P = Scotch pine S = Norway spruce B = European white birch D_{cm} = Diameter breast-high in cm

No. of plot	Stand composition	Age years	Site class	Density	Crown closure	Forest type	H_m/D_{cm} of dominant species	Young growth (Y) Shrub layer (S)	Herb and moss layer	Soil
1	I: 10P	160	III	1.0	0.8	Cowberry-bilberry pine forest	25.0/32.0	Y: - ; S: - .	Medium density, cowberry, bilberry, green mosses	Sandy, fresh
2	I: 10P	120	IV	0.7	0.6	Heather pine forest	21.0/28.0	Y: - ; S: - .	Sparse, cowberry Scotch heather, lichens	Sandy, dry
3	I: 10P	220	Va	0.6	0.5	Ledum-high-bog pine forest	10.0/20.0	Y: medium density, pine 20-80 years; S: - .	Dense, crystal tea ledum, sedges, peat-moss	Peaty, wet
4	I: 8F1S 1Ps+B	110	III	0.8	0.65	Bilberry fir forest	21.0/22.0	Y: medium density, spruce 10-50years S: sparse, mountain ash, bird cherry.	Medium density, stone bramble, wood-reed, wood-sorrel	Loamy, fresh
5	I: Dead trees, 7F2Ps 1S+A	140	III	0.8	0.6	Bilberry fir forest	24.0/28.0	Y: - ; S: medium density, mountain ash, raspberry, dropwort.	Dense, willow-herb, grasses, broadleaved herbs	Loamy, fresh
6	I: 10B	50	III	0.9	0.8	Bilberry birch forest	18.0/16.0	Y: Siberian stone pine, scattered; S: - .	Sparse, horse-tail, cowberry, wood-reed	Dried out peat
7	I: 10A	50	II	0.9	0.8	Wood-sorrel aspen forest	19.0/20.0	Y: - ; S: - .	Sparse, wood-reed, stone bramble, wood-sorrel	Loamy, fresh

dead branches covered by beard-moss (Diag. 34) were measured. Other objects included in the terrestrial study were bark of trees (Diags. 31 and 33), meadows and hay (Diag. 63) and sand with artificial furrows (Diag. 99).

The spectrograph LS-3 was also employed for a number of airborne recordings. These were carried out over the more or less pure forest stands given in Table 5 (see results for Siberian fir forest in Diag. 27 and for dead trees in Diag. 36), over rye fields (Diag. 62), meadows (Diag. 62), bogs (Diag. 65) and fallow (Diag. 93). The LS-3 could be tilted so that measurements from oblique angles were possible, too.

Source: BELOSV59AFL.

2.3 Arkhangelsk area

In 1956 a sample plot was selected on the lower Onega river in the district ("oblast'") of Arkhangelsk. The same group of scientists which did the study in the Tomsk area also conducted the field work in this region. In addition, N.G.Kharin carried out observations on site conditions, phenology, etc.

The study area lies south of the Onega bay and has a rolling relief. The underground consists of Devonian limestone and is covered by quarternary glacial deposits. The soils are sandy or loamy sandy and podzolized. In depressions, peat bogs are found. The climate is characterized by an annual precipitation of 500 - 550 mm and January and July mean temperatures of -12 to -13° C and +15 to +16° C respectively.

The vegetational cover is typical for the northern part of the European taiga with Norway spruce, Scotch pine, pubescent birch and aspen as principal species. Siberian larch is less frequent. Along river courses speckled alder and willows are encountered. Most of the forest stands are dominated by spruce and pine. Pure stands of birch and aspen are very rare. These two species usually are a subordinate component of the spruce and pine forests with a coverage of 10 - 20 %. Larches may cover 10 - 40 % of stands, but only in areas where the limestone is near the surface. The most typical forest type of this region can be described as bilberry mixed forest with 50 % spruce (120 - 180 years old), 40 % pine (130 - 250 years), 10 % birch (80 years) plus some aspen (80 years) and larch (180 - 200 years). Due to the unfavorable climatic and pedologic conditions most stands are of the site class IV or V. 83 % of the area is covered by forest, 14 % by bogs, 2 % by lakes and 1 % by grassland.

Spectral reflectance measurements were carried out between July 3 and August 20. The same instruments and methods as used in the Tomsk study were employed, except for aerial measurements which could not be carried out because of bad weather. A selection of the data obtained is presented in this report (spruce needles in Diag. 9, pine needles in Diag. 12, birch leaves in Diag. 22, aspen leaves in Diag. 23, whole crowns of spruce in Diags. 43 and 45, of pine and birch in Diag. 45, of larch in Diag. 43 and of aspen in Diags. 23 and 43).

Source: BELOSV59AFL, KHARNG60AIT.

2.4 L'vov area

Investigations on the spectral reflectance from tree species and other objects were carried out in the L'vov (Lemberg) area, Western Ukraine, in summer 1958 by a group of scientists of the Laboratory of Aeromethods, Academy of Sciences, comprising V. A. Alekseev, S. V. Belov, I. N. Belonogova, N. M. Voronkova and T. A. Shishkina. The study area lies in the forest steppe belt and contains a great variety of cover types: Forests, meadows, agricultural crops, swamps and lakes. The forests are of the mixed type and are composed of many different species. This is because the area is located in the transitional zone between two floristic regions, the Baltic and the Black Sea region, respectively, and one can find Scotch pine associated with species such as beech and hornbeam, which otherwise is rare. The dominant species among the coniferous trees is Scotch pine, which forms stands on sandy, weakly podzolized soils. Much less numerous are Weymouth pine, spruce and larch. Beech, oak and hornbeam, occurring in pure or mixed stands, predominate among the hardwood trees. Sometimes ash, maples, linden and elms are also associated with them. As representatives of the taiga belt birch, aspen and alder can be found in small numbers (see the description of sample plots in Table 6).

Systematic ground measurements of spectral reflectance at intervals of 2 - 3 weeks during the growing season (June 6 - October 13) were carried out with a photoelectric field spectrometer (see section 1.3.1) and partly with a Universal Photometer FM (see section 1.2.1) on branches of the following tree species (for the preparation of samples see section 1.6.2): Scotch pine (Diags. 1 - 3, 46, 48 and 52), Weymouth pine, Norway spruce (Diags. 4 - 6, 47, 49),

Table 6 Characteristics of sample plots with forest stands in the L'vov area (from ALEKVA60SDP)

P = Scotch pine, O = English oak, B = European white birch, A = Aspen, Be = Beech, H = Hornbeam, L = Linden, M = Sycamore maple, Al = European alder

I = Upper story
II = Lower story
H_m = Tree height in m
D_{cm} = Diameter breast-high in cm

No. of plot	Stand composition	Age years	Site class	Density	Crown closure	Forest type	H_m/D_{cm} of dominant species	Young growth(Y) Shrub layer (S)	Herb and moss layer	Soil
1	10P+O	30	Ia	0.9	1.0	Fresh subor (B_2)	15/14	Y: – ; S:willow, sparse.		Loamy-sandy, fresh, on sand
2	10P(+O)	45	Ia	1.1	1.0	Fresh subor (B_2)	18.5/21	Y:spruce, sparse; S:hazelnut, dense.	Grasses, broad-leaved herbs	Loamy-sandy, fresh, on calcareous loam
3	I: 10B (+A)	50	I	1.0	0.9	Fresh subor (B_2)	20/22	Y:beech, hornbeam, sparse; S:hazelnut, sparse.	Grasses, pilose sedge	Loamy, fresh
	II: 6Be 3H1L	30		0.3			14/14			
4	10P	50	Ia	1.3	1.0	Fresh compound subor (C_2)	22/28	Y:beech, hornbeam, sparse; S:hazelnut medium density.	Wood-sorrel, maianthemum	Loamy-sandy, fresh, on sand
5	9P1Be (+O,H)	110	I	1.3	0.9	Fresh compound subor (C_2)	28/38	Y:beech, hornbeam, sparse; S:hazelnut sparse.	Maianthemum, wood-sorrel	Loamy-sandy, fresh
6	8Be1O1H +B,M	65	I	0.8	0.9	Fresh beech forest (D_2)	23.5/30	Y:beech, sparse; S: – .	Broadleaved herbs, pilose sedge	Humus carbonatic, loamy sand, fresh
7	10Al	40	I	0.9	0.8	Alder swing moor	19/18	Y: – ; S:hazelnut scattered.	Ferns, nettle	Sod gley, sandy, wet

larch, European white birch (Diags. 18, 46, 48, 50 and 51), aspen (Diags. 47, 49 and 52), beech (Diags. 16, 17, 46, 48, 51 and 52), hornbeam, English oak (Diag. 50), ash (Diags. 47, 49 - 51), sycamore maple, European alder and brittle willow.

Irregular measurements were also conducted on other trees and shrubs, namely on linden, juniper, hawthorn, common pear, elder, hazelnut, Persian walnut, alder buckthorn, buckthorn, wartybark euonymus, spindle-tree, snowball, false acacia and sweet cherry.

In addition, reflectance recordings of a number of other objects were obtained. These included bark of trees (Diag. 32), agricultural crops such as oats (Diags. 39 and 61), rye (Diag. 61), corn, potatoes, beets, flax and lupines, lowland and upland meadows, road surfaces, without and with pavement (Diags. 95 and 96), moor (Diag. 66) and sandy and loamy soils (Diags. 39, 81, 94 and 97).

Airborne measurements of the reflectance of whole forest stands (see Diags. 10, 25, 28, 29 and 55) were conducted with the aerial spectrograph LS-3, which was equipped with a false color film of the SN-2 type (see section 1.4.1). A number of more or less pure stands with high crown closure were selected. A description of their properties is provided by Table 6. In order to investigate the influence of light and shadow sides on remission the instrument was tilted and oblique observations were taken from various directions (Diags. 25, 28 and 29).

Source: ALEKVA60SDP.

2.5 Northern Kazakhstan

Systematic investigations on the influence of various soil properties on reflectance were undertaken by J.S.Tolchel'nikov and I.L.Belogonova of the Laboratory of Aeromethods, Academy of Sciences of the USSR, under the direction of V.P.Miroshnichenko. Soil samples were collected from a variety of soil types in the steppe and dry steppe zone of Northern Kazakhstan.

Among the soil-forming rocks of the study area, quaternary loesses and loess-like sediments as well as a red weathering crust with a high iron oxide content are the most widely distributed. The zonal soil types of the area are chernozems and chestnut soils. Saline, sodic and related soils, such as solonetzes

and soloths, occur in basins with bad drainage and groundwater influence.

During the field work, soil profiles and properties of the soil surface were studied in detail. Samples were collected from the surface layer of soils and sample points were noted on air photographs taken at the time of the field survey.

In the laboratory the samples were analized with respect to granulometric, mineral and chemical composition and content of humus, iron oxides and moisture (see results of analysis in Table 31).

Reflectance measurements were carried out by means of a Universal Photometer see section 1.2.1; for the preparation of samples see (section 1.6.1) and an attempt was made to explain the reflectance characteristics with the soil properties. Results of measurements are shown for chernozems in Diags. 88, 109 and 110, a chestnut soil in Diag. 89, a solonetz and a soloth in Diag. 110. In addition, for a comparison and a more systematic investigation, the laboratory work also included the measurement of artificially prepared samples of various salts (see Diag. 76), humic acids (Diag. 77), iron oxides (Diag. 78), minerals (Diags. 79 - 80), grain size categories (Diags. 82 - 87) and moisture contents (Diags. 88 and 89).

Sources: BELOIN59ZSJ, TOLCJS60PFT, TOLCJS66DAP[11].

2.6 Caspian lowland

In a study on the possibility of employing terrain and cover types as indicators for groundwater surveying in the Caspian lowland (especially in the regions of the Sarpinian lakes and the Tajsojgan sands), E.S. Arcybshev of the Laboratory of Aeromethods, Academy of Sciences, measured the spectral reflectance of some soil and vegetation types on the ground by means of a Universal Photometer FM (see section 1.2.1).

The Caspian lowland lies within the semi-desert belt (see map). The annual precipitation amounts to about 200 mm. It is distributed more or less evenly over the year and has a weak maximum from May to June. Due to a slow change to a somewhat more humid climate, the area is presently in a process of desalinization. During winter a thin snow cover is usually formed. The rivers are, in general, intermittent without clearly marked beds and do not reach the Caspian Sea, except in times of high floods. The soil-forming rocks of the area consist

of clays, loess-like loams and sand. Being marine sediments deposited by the Caspian Sea during a former transgression period, they are salt-bearing.

The relief of the study area can be characterized by a sequence of depressions (limans[12]), which may be several meters deep and vary in size from some m^2 to several hundreds of ha, and intervening higher lying areas (Russ.: "plakor"), often with smaller shallow depressions (Russ.: "padiny"). Two types of limans can be distinguished:

a) Linear limans (Russ.: "lozhbiny"), which are narrow channels, often stretching over a considerable distance, and b) round limans (Russ.: "zapadiny") (see Fig. 32). The linear limans are said to be old drainage channels.

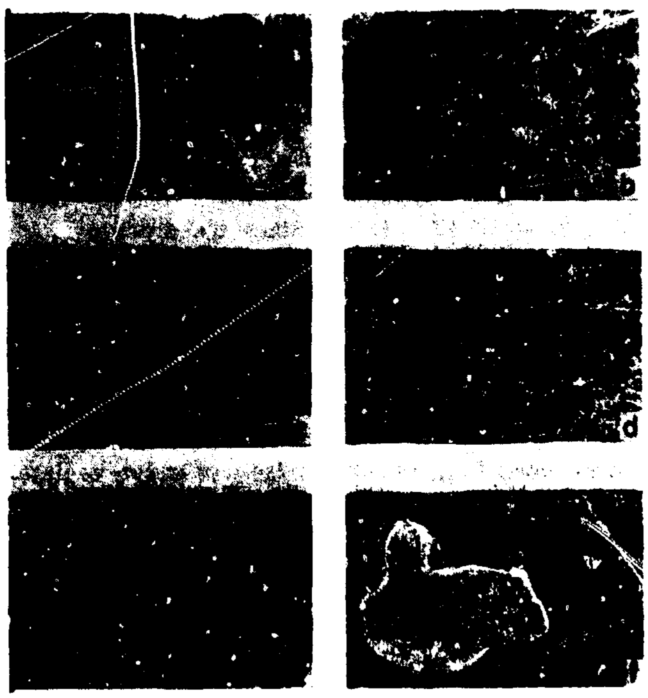


Fig. 32

Appearance of various types of depressions in the Caspian Lowland on panchromatic air photographs. Scale approx. 1:25,000 (from ARCYES61SEL). Indicators of fresh groundwater: a = round liman ("zapadina"), b = linear liman ("lozhbina"), c = deflation basin ("kotlovina vyduvanija"), d = shallow depression ("padina"); Indicators of saline groundwater: e = round liman ("zapadina"), f = solonchak depression.

Each type of depression has its own hydrological regime and its own process of soil formation which depends on the intensity of the percolation of flood, rain and snow water. The linear limans are also called "open limans", because they are connected to the river system and flooded almost every year. The round limans, on the other hand, are "closed", i.e., they do not have a connection to the river system and their water supply depends on rain and melt-

water flowing down from the surrounding terrain. In many limans and river beds, the spring percolation of fresh water results in a desalting of the top soil and in an accumulation of humus and moisture and has lead to the formation of lenses of fresh groundwater, lying usually at a depth of 1.5 - 5 m over a compact horizon of saline groundwater. The associated soils are of the meadow-chestnut type and the vegetation consists of mesophytic plants, especially various species of couch-grass. The lowest parts may be marshy and covered by reed. In some cases, however, the limans are underlain by saline groundwater only. Under such circumstances, one finds saline meadow-chestnut soils, solonchaks and solonetzes or even actual saltpans (Russ.: "sort"). The latter are salt lakes during a part of the year and, after drying out, have a solonchakous surface. Typical plants in saline depressions are the white polyn and the annual saltwort. As a rule, limans with saline groundwater show an abrupt boundary, with respect to their soil and vegetation cover, often marked by a bright frame of salt efflorescences. This is in contrast with the fresh groundwater limans, where there is a gradual transition to the surrounding terrain.

The elevated flat terrain (Russ.: "plakor") is plateau-like and well-drained and the groundwater is at a depth of 10 - 12 m. Since the process of desalinization occurs more slowly on this type of terrain, the soils are more or less saline and predominantly of the solonetz type. Accordingly, the vegetation cover is sparser than in the fresh water limans and consists of xerophytic and halophytic species, such as bijurgun.

The shallow depressions ("padiny") on the upland terrain are 10 - 30 cm deep and frequently circular in shape (see Fig. 32). Their type of water regime is between that of fresh water limans and that of the level "plakor" surface, i.e., the groundwater underneath is less mineralized and the vegetation cover is denser than on the surrounding flat terrain.

Some parts of the Caspian lowland are covered by aeolian sands which form either a stable and flat cover or consist of moving barkhan dunes. The sand-covered areas act as collectors of percolation water and, therefore, give rise to the formation of fresh groundwater. The vegetation, consisting of sand polyn, licorice and other species, is especially concentrated in areas where the groundwater is relatively near to the surface, i.e., on the marginal parts of the sand and on deflation basins.

Selected examples for the spectral reflectance of indicators of fresh groundwater are presented in Diags. 68, 70, 73 and 74; for that of indicators of saline groundwater, in Diags. 71, 72 and 75.

Sources: ARCYES61SEL, ARCYES62ISJ.

3. Results of measurements: Vegetation

3.1 Spectral reflectance of trees

In the following we shall make an attempt to order the results of reflectance measurements into a number of sections which will deal with various factors affecting reflectance, such as season, exposure, site condition, angle of observation, etc. A comparison of species will be provided at the end of this part. Before doing so, however, it may be useful to remember some of the basic facts associated with reflectance of vegetation.

Healthy green vegetation has reflectance minima in the blue and red (at about 375 mμ) and a maximum in the green (at 550 mμ) portion of the visible spectrum. This property can be explained by the absorption characteristics of chlorophyll (see Fig. 33). Above 680 mμ there is a sharp upswing in reflectance,

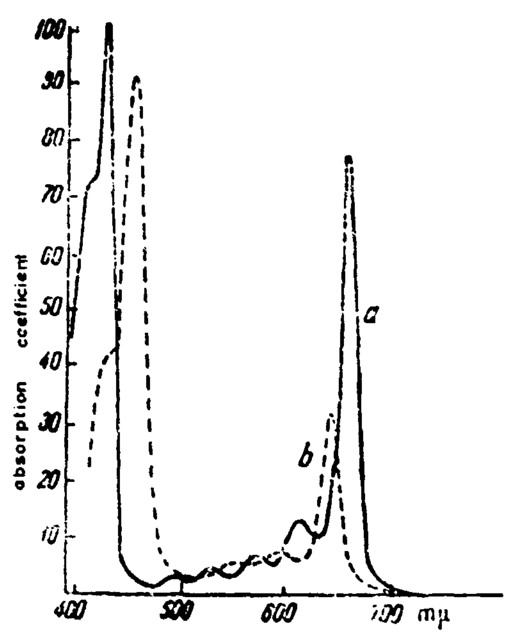


Fig. 33 Spectral absorption characteristics of chlorophyll a and b (after V. Ljubimenko[13], from ILINAA47SPO).

which then remains high throughout the whole near infrared zone. Investigations of chlorophyll extractions have shown them to be completely transparent. In Diag. 37 the transparency of a single birch leaf in the infrared is demonstrated by the comparison of spectral reflectance curves obtained for three different backgrounds,

namely white paper (reflectance 90 %), gray paper (55 %) and black paper (6 %). It can be seen that, with a dark background, the intensity of radiation recorded drops considerably. In the visible part of the spectrum all curves coincide (ILINAA47SPO). The high remission values in the infrared region observed for healthy vegetation are caused by the internal plant tissue, which reflects infrared radiation heavily. This is especially true for the spongy parenchyma of leaves. In needles this kind of mesophyll is absent, which explains the well-known contrast between deciduous and coniferous forests with respect to infrared reflectance.

As soon as leaves of deciduous species begin to wilt in fall, the high infrared remission drops. With the loss of the chlorophyll and the onset of the fall coloration the reflectance maximum in the green and the minimum in the red part of the spectrum disappear and the spectral curve takes a more regular shape with a steady upward trend from the lower visible wavelengths to the infrared (see below).

3.1.1 Reflectance as a function of season (phenology): Deciduous hardwood trees

Seasonal changes are most conspicuous with deciduous hardwood trees. Various sources, among them especially the data collected by V.A.Alekseev and S.V.Belov in the L'vov area (see section 2.4) by measuring leaves on the ground, permit the following conclusions:

1. The foliage has a high reflectance after leafing out: Although reflectance measurements were not started before June, it can be seen that the first curves recorded indicate a higher reflectance than those obtained later in the summer and early fall (see Curves 16.1 for beech, 18.1 for birch, 50.2 for ash and 50.3 for English oak, respectively). This is caused by a low chlorophyll content and, consequently, a light green color of the leaves. The shape of the curves is that typical for green vegetation as explained above. Average reflectances are 6 - 9 % in the blue, 10 - 15 % in the green, 8 - 14 % in the red and 72 - 77 % in the infrared portion of the spectrum (see Table 7).

2. The reflectance drops at all wavelengths more or less steadily from the period of leafing out until the beginning of the fall color change. This is illustrated by sequential measurements taken on beech foliage (Curves 16.1 - 17.1). Similar results were obtained for leaves of birch (see Curves 18.1 and 18.2), aspen, maple, (probably Sycamore maple) ash (see Curves 50.2 and 51.3) and English oak. Until the middle of September average reflectances drop to 4 - 8 %

Table 7 Seasonal changes of the reflectance (%) of deciduous tree foliage in the L'vov area for selected spectral intervals (based on data reported in ALEKVA60SDP)

SRC no. = Spectral reflectance curve number

Spectral region		Beech	European white birch	Aspen	Maple	Ash	English oak
Green leaves in early summer							
	Date	VII-16	VI-17	VII-16	VI-7	VI-7	VI-8
	SRC no.	16.1	18.1,50.1			50.2	50.3
Blue (450-490 mμ)		5.8	8.9	7.1	7.8	7.5	6.3
Green (510-590 mμ)		10.2	14.8	11.7	10.3	10.2	15.0
Red (610-690 mμ)		7.9	14.0	8.9	9.0	7.3	9.7
Infrared (710-890 mμ)		76.0	76.6	75.4	76.0	70.0	72.0
Green leaves in early fall							
	Date	IX-14	IX-14	IX-14	IX-14	IX-14	
	SRC no.	16.3					
Blue		4.3	7.7	5.0	4.8	3.9	
Green		8.2	12.2	8.9	7.4	5.9	
Red		6.5	9.8	6.6	5.9	4.5	
Infrared		60.7	57.0	51.6	56.3	55.1	
Green or yellow-green leaves at beginning of fall coloration							
	Date	IX-29	IX-30	IX-30	IX-29	IX-29	IX-30
	SRC no.	17.1	18.2				
Blue		3.0	4.3	5.2	3.9	3.5	5.4
Green		6.2	8.7	10.9	7.1	11.4	8.1
Red		4.6	6.6	7.4	5.3	7.4	6.0
Infrared		36.9	35.6	47.0	52.6	50.0	51.2
Yellow or yellow-orange leaves							
	Date	X-1	X-11	X-11	X-11	X-12	X-2
	SRC no.	17.2	18.3,48.2	49.2		49.3	
Blue		3.7	9.3	5.6	6.1	5.7	6.7
Green		16.9	30.5	22.3	19.6	17.8	16.6
Red		24.5	43.6	30.0	27.1	11.6	21.6
Infrared		47.2	55.5	47.8	47.9	53.3	51.9
Dry brown leaves							
	Date	X-11		X-11			
	SRC no.	52.1		52.2			
Blue		2.8		6.6			
Green		5.7		8.2			
Red		10.7		10.7			
Infrared		21.3		16.3			

in the blue, 6 - 12 % in the green, 4 - 10 % in the red and 52 - 61 % in the infrared spectral region (see Table 7). An exception to the rule of constant decrease is Curve 16.3 (reflectance of beech leaves on September 14), which is higher than 16.2 (July 31) within the visible spectrum. A corresponding deviation was observed for birch. The authors do not comment on this phenomenon. It may be due to sampling errors or be associated with other factors such as changes of moisture stress.

3. It seems that reflectance becomes lowest at the very beginning of the coloration when leaves are still green as suggested by Curves 17.1 (beech) and 18.2 (birch), recorded at the end of September. Average reflectances reach a minimum with 3 - 4 % in the blue, 6 - 9 % in the green, 5 - 7 % in the red and 36 - 37 % in the infrared (see Table 7). It is above all striking that the infrared remission of beech and birch gets more intensive again later on, because, as mentioned in the introduction above, the general notion is that infrared reflectance is relatively high until the leaves begin to wilt and then drops steadily. Whether this seasonal minimum of infrared reflectance is typical for beech and birch only or whether it was missed by the other measurements and, in fact, is common to all deciduous species, cannot be decided.

4. In the early stage of the fall color change when leaves are yellowish-green, the reflectance has a tendency to become more intensive in the green and red part of the spectrum, whereas the remission intensity of blue light remains more or less constant. As can be seen from Table 7, the reflectance averages of ash and aspen on September 29 and 30, respectively, were about the same for the blue wavelengths as on September 14, namely approximately 4 % and 5 %, respectively. On the other hand, in the same time they increased from 6 % and 9 %, respectively, to about 11 % in the green and 4 1/2 % and 6 1/2 %, respectively, to 7 1/2 % in the red zone. In the infrared there was a slight decrease from 55 % to 50 % and from 52 % to 47 %, respectively. During the same time interval the maple did not show any distinct change in reflectance (see Table 7). It must be assumed that, compared with the other species, the fall phenology of maple is less far developed at the end of September. The shape of the spectral remission curve of yellow-green leaves is still that typical for green vegetation, i.e. with the maximum at 550 mμ and the minimum at about 675 mμ as long as there is still some chlorophyll concentration in the leaves. An example of such a curve is provided in Diag. 20, where Curve 2 represents the spectral reflectance of green-yellow maple leaves (based on data reported by A.K. Pronin).

5. With the coloration proceeding further the leaves become red, orange or yellow. This period is associated with the loss of the green maximum and the red absorption minimum and, as a result, the general reflectance of the visible light shows an upward trend and leaves become more reflective in the red than in the green spectral band. Averages are now between 4 and 9 % in the blue, 17 and 30 % in the green and 22 and 44 % in the red portion of the spectrum. The infrared returns remain on about the same level as before and vary between 47 and 56 %. The shape of the spectral curves can now be described by a sharp upswing between 500 and 600 mμ and a slight but constant increase above 600 mμ up to 900 mμ (see Curves 17.2, 18.3, 19.2 + 3 and 20.3 for beech, birch, aspen and maple, respectively, and also 49.2 for aspen).

As one would expect from the color, the sharp increase in reflectance occurs at about 500 mμ for yellow and at about 600 mμ for red leaves (see comparison of curves 2 and 3 in Diag. 19).

Ash is an exception in that its leaves remain yellow-green until their fall. Consequently, although the general reflectance increases, the spectral remission curve keeps the shape which is typical for green vegetation (see Table 7 and Curve 49.3).

6. In some instances dry brown leaves were also measured. Compared with the situation at the time of coloration, they become much less reflective (see Table 7). The average reflectance is about 3 - 7 % in the blue, 6 - 8 % in the green, 11 % in the red and 16 - 21 % in the infrared spectral zone. The spectral reflectance now becomes an almost linear function of wavelength as demonstrated by Curves 17.3 and 52.1 (beech) and 52.2 (aspen). The 2- to 3-fold increase of reflectance from the visible to the infrared spectrum is typical for recently withered leaves. After some time the curves become flatter. It should be noted that the color change may take place at different times for various species and that the same species may undergo this phenological stage sooner or later, depending on site conditions. As reported by N.G.Kharin from the Arkhangelsk area, birch starts to change its color and drop its leaves first in highbog pine and highbog spruce forests. The corresponding phenological stages in bilberry spruce forests belonging to site classes III or IV occur about 10 to 15 days later. The leaf color change of aspen begins later than that of birch; however, full coloration is reached about 5 - 10 days earlier. Kharin also states that leaves of the same tree species may exhibit a color variation from one type of forest to another. In bilberry pine forests birch leaves are light yellow with an orange hue, whereas in highbog pine and spruce forests they have rather an orange-red tone.

Sources: ALEKVA60SOP, BELOSV59AFL, PRONAK49IRA, KHARNG60AIT.

3.1.2 Reflectance as a function of season (phenology): Coniferous trees

The larch, being a coniferous tree with deciduous needles, shows seasonal changes of reflectance which are intermediate between those of hardwood trees and those of evergreen coniferous species. Ground data obtained by Z. L. Petrushkina in Western Yakutia and reported by V.M. Bakhvalov are presented in Diagr. 21. Curve 2 represents the reflectance of green, Curve 1 that of yellow needles. The latter is higher in the red part and lower in the green and infrared parts of the spectrum, but the change of reflectance characteristics is, at least in the visible region, less conspicuous than for hardwood species.

Coniferous trees other than larch do, of course, not show a fall color change. Nevertheless, they undergo distinct seasonal changes. Each year the formation of a certain amount of new needles takes place at the beginning of the growing period. Moreover, as for the deciduous trees, a general drop of reflectance throughout the growing season can be observed. This decrease is especially pronounced for young needles, but it takes place also with old needles (one or more years old). The following conclusions can be drawn from ground measurements carried out by V.A. Alekseev, E.S. Arcybashev, S.V. Belov and others in the Leningrad, Tomsk and L'vov areas (see sections 2.1, 2.2 and 2.4):

1. Early in the growing season, new shoots have young light-green needles which are highly reflective: 4 - 8 % in the blue, 9 - 18 % in the green, 5 - 12 % in the red and 50 - 60 % in the infrared spectral region (see Table 8). The shape of the spectral reflectance curves in general conforms with that typical for green vegetation (see Curves 4.1 for Norway spruce and 6.1 for spruce). The curves recorded for Scotch pine around June 20 in both the L'vov and the Leningrad areas show some deviation in that there is no clear minimum in the red spectral band. Instead, the latter is almost flat. This result can be explained by the presence of gray-brown scales on the new pine shoots at the time of measurement.

2. The reflectance of young needles drops steadily during the growing period, first rapidly, then more slowly (see Diags. 1 (Scotch pine), 4 (Norway spruce) and 6 (spruce)). It decreases about 1½ - 3 times in the visible and about 1½ times in the infrared region between June and the end of September (early October in the L'vov area), about 3 - 5 times between June and early

Table 8 Seasonal changes of the reflectance (%) of young needles of some coniferous trees for selected spectral intervals (based on data reported in ALEKVA60SDP, ARCYES58OSD and BELOSV59AFL)

SRC no. = Spectral reflectance curve number
* = Data incomplete for the spectral interval specified

Spectral region	L'vov area		Leningrad area		Tomsk area		
	Scotch pine	Norway spruce	Scotch pine	Norway spruce	Scotch pine	Siberian fir	Siberian stone pine
Early summer							
Date / SRC no.	VI-20 / 1.1	VI-7 / 4.1	VI-22	VI-22 / 6.1	VII-5	VII-5	VII-5
Blue (400-490 mμ)	7.8*	7.7*	6.5*	4.1*	7.3	3.4	5.4
Green (510-590 mμ)	12.9	13.2	12.1	13.2	13.1	9.3	18.0
Red (610-690 mμ)	11.7	12.5	12.0	8.4	9.4	5.4	10.8
Infrared (710-890 mμ)	59.1	53.0	-	-	-	-	-
Late summer or fall							
Date / SRC no.	X-12 / 1.3	IX-29 / 4.3	IX-9	IX-9 / 6.3	VIII-18	VIII-10	VIII-18
Blue	4.8*	2.7*	1.5*	1.4*	3.8	1.8	4.8
Green	7.6	5.1	2.8	3.9	6.6	5.8	8.5
Red	4.4	4.6	2.4	3.0	5.3	3.9	5.3
Infrared	35.6	40.4	-	-	-	-	-

September in the Leningrad area (data for visible radiation only) and about 1½ - 2 times between early July and the middle of August in the Tomsk area (data for visible radiation only). As shown by Table 8 the reflectance percentages in late summer and fall vary between 1½ and 5 % in the blue, 3 and 8 % in the green, 2½ and 5 % in the red, and 35 and 40 % in the infrared portion of the spectrum. The shape of the reflectance curves remains more or less unchanged (see Diags. 4 (Norway spruce) and 6 (spruce)), except for pine, where until fall

Table 9 Seasonal changes of the reflectance (%) of 1 to 2 years old needles of some coniferous trees for selected spectral intervals (based on data reported in ALEKVA60SDP, ARCYES530SD and BELOSV59AFL)

SRC = Spectral reflectance curve
* = Data incomplete for the spectral interval specified

Spectral region (mμ)	L'vov area		Leningrad area		Tomsk area		
	Scotch pine	Norway spruce	Scotch pine	Norway spruce	Scotch pine	Siberian fir	Siberian stone pine
Early summer							
Date	VI-8	VI-7	VI-22	VI-22			
SRC no.	2.1	5.1		7.1			
Blue (400-490)	5.4*	4.6*	2.0*	1.5*			
Green (510-590)	7.6	6.8	3.7	3.7			
Red (610-690)	6.3	6.2	2.9	2.7			
Infrared (710-890)	33.0	29.3	-	-			
Middle of summer							
Date	VII-16	VII-31	VII-6	VII-6	VII-5	VII-5	VII-5
SRC no.	2.3	5.2 47.1		7.2			
Blue	3.5*	2.5*	2.7*	2.[illegible]*	4.0	1.7	5.6
Green	5.3	4.7	5.1	4.4	8.2	6.0	12.2
Re	4.1	4.6	3.3	3.3	6.3	4.3	8.6
Infrared	25.1	25.8	-	-	-	-	-
Late summer or fall							
Date	X-12	IX-29	IX-9	IX-9	VIII-18	VIII-10	VIII-18
SRC no.	3.3 48.1	5.3		7.3			
Blue	2.8*	1.2*	1.1*	1.0*	3.5	2.3	3.8
Green	4.4	2.8	2.3	1.8	7.4	5.5	6.8
Red	3.3	2.6	1.8	1.5	5.1	4.0	4.5
Infrared	18.7	20.7	-	-	-	-	-

the flat part of the curve mentioned above disappears and is replaced by the characteristic pronounced minimum around 675 mμ.

3. A constant decrease of reflectance from summer to fall can also be observed for old needles (1 to 3 years old), although the change is, in general, somewhat smaller than for young needles (see Table 9 and Diags. 2, 3, 5 and 7). For the same time interval as above it amounts to 11/2 - 2 times (from 11/2 - 4 % to 1 - 2 %) in the Leningrad area and to 1.1 - 2 times (from 2 - 12 % to 2 - 7 %) in the Tomsk area. In the L'vov area the decrease is with 11/2 to 4 times rather higher than for young needles. A possible explanation for this phenomenon may be the following:

If one looks at the data obtained in the Leningrad area in Table 9 one sees that the reflectance of old needles is more intensive in early July than in the second half of June. It seems that old needles are first relatively dark, then become brighter and reach a reflectance maxima somewhere in the first half of the growing season before the decrease mentioned above begins. It is possible that the data obtained in early June in the L'vov area, where the growing season starts about 25 days earlier than at Leningrad, fall in this period of maximum reflectance. As far as the Tomsk data are concerned, no conclusions with respect to a reflectance maximum can be drawn. Particular phenological stages there occur at about the same time as around Leningrad, and the first measurements were taken only in early July.

4. There is a contrast between young and old needles throughout the whole growing season, young needles being consistently brighter (see comparison of young and old spruce needles in Diag. 13). The drop in reflectance associated with the increasing age of needles must, to some extent, be a function of the chlorophyll content. V.N. Ljubimenko[14)] found 11.9 % and 20 % chlorophyll in young spruce and pine needles, respectively, but 22.5 % and 30.5 %, respectively, in two year-old needles.

Sources: ALEKVA60SDP, ARCYES58OSD, BELOSV59AFL.

3.1.3 Reflectance as a function of tree age

According to V.A. Alekseev and S.V. Belov, reflectance tends to decrease with increasing tree age. In Diag. 10 measurements taken from the air over two stands of Scotch pine, one 30 years, the other 110 years old, are compared. These are the data on which Alekseev and Belov based their conclusion. This

comparison shows, however, that, except for the infrared part, the reflectance from the older stand is not lower. To some extent, this may be due to inaccuracies in the original drawings, but a difference between young and old stands, if at all present, in any case cannot be very great.

Source: ALEKVA60SDP.

3.1.4 Reflectance as a function of the exposure of leaves and needles

The reflectance of the surface of leaves and needles depends very much on the exposure of the surface in question, i.e., on the amount of light falling on it. It can be observed that leaves and needles grown under conditions of low illuminance reflect heavily and vice versa. Consequently, there is a contrast between the upper and lower side of leaves (see examples in Diags. 22 and 23), between leaves and needles growing in the upper and those growing in the lower part of crowns (Diags. 8 and 24), between leaves and needles growing on the southern and those growing on the northern side of crowns (Diag. 12) and between leaves and needles from overstory and understory trees (Diag. 9). Results obtained by S.V.Belov et. al. are summarized in Table 10. The ratio of visible light reflectances between "shadow" and "light" leaf or needle surfaces is about 4 for willow, 3 for aspen, 2 for birch and 1.5 for coniferous species. In the infrared zone the contrast is smaller and amounts to 1.2 : 1 for willow. For the other species no infrared data have been reported.

It seems that no significant change of color is associated with the change of general reflectance, except perhaps for the lower side of leaves for which spectral curves have some tendency to lose the clear absorption maximum in the red spectral region (see Diag. 22).

That "shadow" and "light" surfaces of leaves and needles behave differently with respect to reflectance can be explained by differenes in anatomical structure and content of chloroplasts, as illustrated by Fig. 34. It was observed experimentally by Ljubimenko[14] that, with an increase in illuminance, the content of chlorophyll decreases, whereas the content of carotine and xantophyll increases absolutely or relatively (see data in Table 11). N.A.Bajdalina[15] investigated the anatomical and physiological properties of young spruce trees growing under various conditions of illumination. She found that "shadow" needles were thinner and had less chlorophyll by a factor of 2 to 2.5. The fact that differences between reflection from "light" and "shadow" surfaces are smaller in the infrared

Table 10 Reflectance (%) of "light" (L) and "shadow" (S) surfaces of various leaves and needles (based on data reported in ALEKVA60SDP, ARCYES580SD, BELOSV59AFL and KHARNO60AIT)

SRC = Spectral reflectance curve
* = Data incomplete for spectral interval specified

Species (Location, Date)	Visible region (400-690 mμ)			Infrared region (710-890 mμ)			SRC no.
	L %	S %	Ratio S/L	L %	S %	Ratio S/L	
Upper and lower sides of leaves							
Brittle willow (L'vov, IX-15)	5.0*	20.4*	4.1	48.4	57.8	1.2	
Europ. white birch (Leningrad, VII-12)	4.4*	9.1*	2.1	-	-	-	
Aspen (Leningrad, IX-9)	3.7*	12.6*	3.4	-	-	-	
Pubescent birch (Arkhangelsk, VII-6)	6.4*	13.3*	2.1	-	-	-	22.1/22.2
Aspen (Arkhangelsk, VIII-20)	6.8*	19.0*	2.8	47.4*	60.6*	1.3	23.2/23.3
Leaves and needles from upper and lower part of crowns							
Spruce (Leningrad, IX-9)	1.6*	2.3*	1.4	-	-	-	8.1/8.2
Europ. white birch (Leningrad, IX-9)	2.7*	4.8*	1.8	-	-	-	24.1/24.2
Needles from southern and northern part of crowns							
Scotch pine (Arkhangelsk, VIII-9)	7.8	10.5	1.3	-	-	-	12.2/12.1
Needles from overstory and understory trees							
Spruce (Arkhangelsk, VII-10/12)	3.2*	4.2*	1.3	-	-	-	9.2/9.1

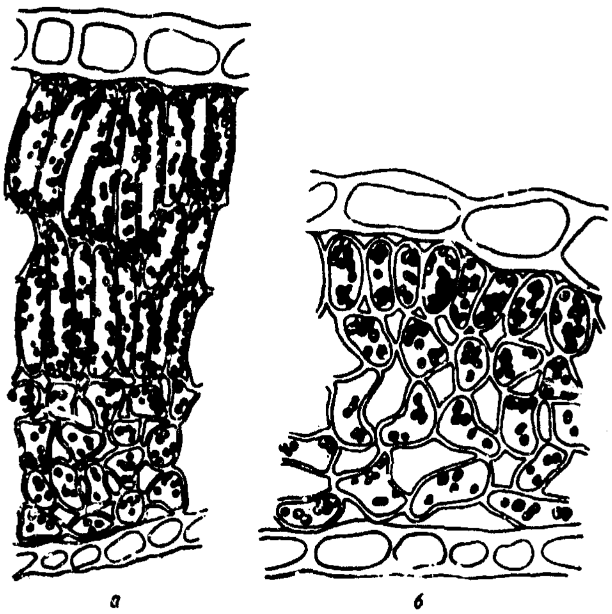


Fig. 34
Cross sections through a "light" leaf (a) and a "shadow" leaf (b) of Norway maple, showing the difference in anatomical structure and chlorophyll content (after V. Ljubimenko and Forsh, from BELOSV59AFL).

Table 11 Relative quantities of chloroplasts in plant cells as a function of illuminance (after V.N. Ljubimenko, from BELOSV57IOS)

Chl = Chlorophyll Car = Carotine Xan = Xantophyll

Illuminance	Pine			Spruce		
	Chl	Car	Xan	Chl	Car	Xan
Diffuse day light	100	100	100	100	100	100
Incident light weakend by 1 sheet of paper	85.4	63.7	137.8	102.5	106.6	106.3
id., 2 sheets	72.0	59.9	127.4	98.3	97.9	93.3
id., 3 sheets	63.8	55.1	104.3	-	-	-
id., 4 sheets	56.6	46.7	104.0	76.0	73.4	73.2
id., 5 sheets	47.1	41.9	88.5	-	-	-
id., 6 sheets	46.7	39.7	77.7	67.3	65.2	70.0
Darkness	25.0	12.5	46.8	45.5	55.9	60.8

part of the spectrum demonstrates that, since chlorophyll is very much transparent to infrared radiation and does not affect its reflection, this small change is caused by the difference in structure of plant tissues. The larger contrast within the visible spectral region must then be due mainly to the change in chlorophyll content.

Some idea about the difference of illuminance on "light" and "shadow" leaf surfaces may be obtained from Diag. 22. Here Curve 22.2 represents the reflectance of the lower side of birch leaves when exposed to the same amount of light as falls on the upper surface (Curve 22.1). Curve 22.3 shows the intensities of the light reflected from the lower surface recorded under simulated natural conditions, i.e., when this surface is in the shadow. Please note that values outside the 500 - 550 mμ range were too low to be shown in the plot. From a comparison of Curves 2 and 3 it can be concluded that the ratio between the light incident on the upper side and that falling on the lower side is about 15.

The difference in the reflective power of upper and lower sides of leaves may have a practical importance for air photography, when, with windy weather, many lower surfaces are being exposed. It is well known that wind will especially disturb leaves with long petioles, such as leaves of aspen.

Source: ALEKVA30SDP, ARCYES58OSD, BELOSV59AFL, BELOSV57IOS, KHARNG60AFF.

3.1.5 Reflectance as a function of site conditions

Site conditions influence the metabolism of plants and the anatomical structure of leaves and needles, and this again gives rise to a change in reflectance. N.G. Kharin made a systematic study of this influence in the Leningrad area. He collected leaves and needles from the upper parts of crowns between June 20 and July 1. At this time, birches and aspens had just reached full leaf development, but the leaves were still light-green. Pine and spruce needles were 1 to 2 years old. The results of his reflectance measurements are summarized in Table 12 and representative spectral curves are presented in Diags. 14 and 15.

From these data it can be concluded that a deterioration of site conditions gives rise to an increase in reflectance. From one site class to the next this increase may vary between 7 1/2 and 20 %.

As far as the spectral distribution of reflected light is concerned, there is a tendency for the green maximum to be shifted from 550 to 570 mμ with a deterioration of site (see Diags. 14 and 15). As a whole, however, the shape of the spectral curves and, consequently the color remain very much the same.

Similar observations by N.G. Kharin in the Arkhangelsk area confirmed the above findings.

Table 12 The dependence of visible light reflectance of leaves and needles on site conditions (based on data collected by N.G. Kharin in the Leningrad area, reported in BELOSV59AFL)
SRC = Spectral reflectance curve

Site class	Type of forest	Visible light (450-690 mμ) reflectance in % (SRC no. in parentheses)			
		Spruce	Pine	Birch	Aspen
V	Highbog pine forest		6.4 (14.1)		
	Highbog birch forest			11.7 (15.1)	
IV	Haircap-moss spruce forest	5.8			
III	Bilberry spruce forest	4.1			
	Bilberry pine forest		5.5 (14.2)		
	Bilberry birch forest			9.7 (15.2)	
	Bilberry aspen forest				8.2
II	Wood-sorrel spruce forest	3.5			
	Wood-sorrel pine forest		4.7 (14.3)		
I-II	Wood-sorrel birch forest			9.0 (15.3)	
I	Wood-sorrel aspen forest				7.1

In Table 13 some airborne measurements taken by S.V. Belov et. al. in the Tomsk area over pine stands of different site classes are compared. Again there is an increase of reflectance with deteriorating site in the visible part of the spectrum. At the same time, the data obtained in the infrared seem to indicate that there is only a smaller increase or even a decrease of remission. With this small number of measurements a reliable conclusion cannot be drawn, however.

Sources: BELOSV59AFL, KHARNG60AIT.

Table 13 The dependence of reflectance of pine stands on site conditions (based on airborne measurements in the Tomsk area, Sept. 12-15, reported in BELOSV59AFL)

Site class	Type of forest	Reflectance in %	
		Visible region (550 - 690 mμ)	Infrared region (710 - 790 mμ)
Va	Ledum-highbog pine forest (plot 3 in Table 5)	5.4	31.8
IV	Heather pine forest (plot 2 in Table 5)	4.9	34.1
III	Cowberry-bilberry pine forest (plot 1 in Table 5)	3.6	24.8

3.1.6 Reflectance as a function of climatic conditions

According to G.A.Tikhov (in TIKHGA49ABO and TIKHGA51RRW), plants growing in cold climates have, in general, a lower reflectance than those growing in warm climates. The reason is that, in a cold climate, plants need more solar energy in order to survive and thus absorb more radiation. M.P.Ostjakov (in OSTJMP49SSR) found that spruces growing at an altitude of 2200 m reflected less than spruces at an altitude of 1500 m. The notion of the decreasing reflectance as a function of decreasing temperature should not be generalized too much, however. Plants living in a cold environment often have on their surface protective devices, such as a layer of hair, which in turn may give rise to a higher reflectance again. Reliable conclusions as to the dependence of reflectance on temperature can only be drawn from a comparison of identical or similar species as Ostjakov has done. Furthermore, such a comparison should take the phenology of plants into account.

We can make an attempt at comparing the reflectance data in Table 9, where results obtained in the L'vov, Leningrad and Tomsk areas, respectively, are summarized. Mean July temperatures are about 19° C at L'vov, 16° C at Leningrad and 18° C at Tomsk. If, based on the phenological maps published in the "Atlas SSSR" (see Introduction), we assume that the phenological development in the Tomsk area occurs approximately parallel to that in the Leningrad area, and that corresponding stages in the L'vov area are reached about 20 - 25 days earlier, we can compare the early summer data of L'vov with the midsummer data of Leningrad and Tomsk.

In doing this we find that the reflectance of Scotch pine needles at Tomsk

is of about the same order of magnitude as that at L'vov, and that in both the L'vov and Tomsk areas the reflectance of pine and spruce needles is 1.5 to 2 times higher than at Leningrad. It seems also that the increase is higher in the blue and red spectral regions, i.e., in the chlorophyll absorption bands, than in the green part of the spectrum. This, however, contradicts a statement made by Ostjakov that the difference is most pronounced at 540 $m\mu$.

Sources: BELOSV59AFL, VINOAI55IRP.

3.1.7 Influence of crown and stand structure on reflectance

While reflectance measurements taken on single plant elements, such as leaves or needles, on the ground are valuable from the point of view of a systematic analytical investigation of the laws of reflection of radiation, they may lead to faulty conclusions when used directly to predict tone on air photographs. This is so because from the air one sees not only the leaf surfaces, but also branches, shadows, parts of the soil shining through, etc. Furthermore, leaves are oriented at various angles to the incident radiation and the direction of observation. Therefore, in order to have a reliably predictive value for aerial photography, the reflectance of whole trees or forest stands should be measured from vantage points.

V.A.Alekseev, E.S.Arcybashev and S.V.Belov, in a series of measurements carried out in various regions of the USSR, took spectral recordings of either whole crowns from a tower (see section 1.6.2) or of whole stands from a plane. The crown data were collected for the specific purpose of comparing them with parallel measurements taken on leaves and needles. In the case of the airborne measurements such a direct comparison was not intended. We shall nevertheless try in the following to confront these with ground data which are approximately comparable in terms of phenology, site quality, etc. It should be noted, however, that the conclusions drawn in the latter case are less reliable.

Table 14 compares average percentage reflectances in the blue, green, red and infrared spectral zones. As examples for the change in spectral reflectance from needles or leaves to whole crowns we have selected data for Scotch pine (Diag. 11) and aspen (Diag. 23).

For a comparison of crown with needle or leaf data the analysis of the measurements permits the following generalizing statement: The reflectance of crowns of coniferous trees (excluding larch) amounts to about 75 % of the re-

Table 14 Influence of tree and stand structure on reflectance: Comparison of ground, tower and airborne measurements (based on data reported in ALEKVA60SDP and BELOSV59AFL)
* = Data incomplete for spectral interval specified
SRC = Spectral reflectance curve

Object / Spectral region	SRC no. Date	Reflectance in % Blue	Green	Red	Infrared
L ' v o v a r e a					
Wavelength (mμ)			550-590	610-690	710-890
Scotch pine, young shoots with needles	VII-16		8.6	7.0	41.6
id., old shoots with needles	2.3 VII-16		5.5	4.1	25.1
id., stand (plot 1 in Table 6)	10.1 VII-11		3.5	1.9	24.3*
id., stand (plot 5 in Table 6)	10.2 VII-11		3.7	2.1	22.9*
European white birch, leaves	VII-31		10.3	9.2	51.7
id., stand (plot 3 in Table 6)	28.2 VII-11		3.8	2.4	46.4*
Beech, leaves	16.1 VII-16		10.8	7.9	76.0
id., stand (plot 6 in Table 6)	29.2 VII-11		6.3	3.8	48.7*
L e n i n g r a d a r e a					
Wavelength (mμ)		450-490	510-590	610-670	
Scotch pine, young shoots with needles	VI-22	6.9	12.1	12.0	
id., old shoots	VI-22	3.1	3.7	2.9	
id., stand (plot 1 in Table 4)	58.1 VI-24	2.1	3.6	2.3	
Norway spruce, young shoots with needles	6.1 VI-22	4.4	13.2	8.4	
id., old shoots	7.1 VI-22	1.6	3.7	2 7	
id., stand (plot 2 in Table 4)	58.3 VI-24	1.2	1.7	1.4	
European white birch, leaves	VI-21	3.9	10.9	6.6	
id., stand (plot 3 in Table 4)	58.2 VI-24	2.0	3.7	2.2	

Table 14 (Continued)

Object / Spectral region	SRC no. Date	Reflectance in % Blue	Green	Red	Infrared
Tomsk area					
Wavelength (mμ)		400-490	510-590	610-690	710-790
Scotch pine, young shoots with needles	11.3 VIII-3/7	6.9	10.4	10.6	55.8
id., old shoots	11.2 VIII-3/7	3.3	7.3	6.6	46.3
id., whole crown	11.1,53.2 VIII-3/7	2.4	5.0	5.0	41.6
id., stand (plot 1 in Table 5)	IX-9		5.0*	2.7	24.8
Siberian spruce, young shoots	VIII-4/11	2.7	6.4	5.8	52.3
id., old shoots	VIII-4/11	2.5	5.4	4.9	45.6
id., whole crown	53.1 VIII-4/11	2.1	4.2	3.5	37.2
Siberian fir, young shoots	VIII-7/13	3.0	6.6	6.1	58.6
id., old shoots	VIII-7/13	2.4	5.3	3.8	42.6
id., whole crown	44.1 VIII-7/13	2.0	3.8	4.2	40.4
id., stand (plot 4 in Table 5)	IX-14		2.8*	1.9	24.1
Siberian stone pine, young shoots	VIII-3/7	4.6	8.9	7.4	61.7
id., old shoots	VIII-3/7	3.6	7.4	6.2	45.7
id., whole crown	44.2 VIII-3/7	2.3	4.5	3.9	41.6
Pubescent birch, leaves	VIII-7	5.4	10.2	13.4	72.2
id., whole crown	53.3 VIII-7	3.9	5.6	4.7	51.7
Aspen, leaves	VIII-7/12	5.1	12.4	9.5	70.3
id., whole crown	44.3 VIII-7/12	3.4	5.6	4.7	51.7

Table 1.4 (Continued)

Object / Spectral region	SRC no. Date	Reflectance in % Blue	Green	Red	Infrared
A r k h a n g e l s k area					
Wavelength (mμ)		430-490	510-590	610-690	710-790
Norway spruce, young shoots	VII-3	3.4	7.8	4.1	21.9
id., old shoots	VII-3	2.4	4.6	3.5	17.2
id., whole crown	43.1 VII-3	2.2	3.1	2.9	19.0
Norway spruce, young shoots	VII-7	4.0	8.4	3.9	28.8
id., old shoots	VII-7	2.3	4.3	2.2	18.8
id., whole crown	45.1 VII-7	1.6	3.2	2.6	14.9
Siberian larch, new and one year old shoots	VIII-14	4.2	8.8	5.3	30.1
id., whole crown	43.2 VIII-20	2.3	4.9	3.6	17.0
Aspen, leaves	23.2 VIII-20	4.9	9.3	5.7	47.4
id., whole crown	23.1, 43.3 VIII-20	2.8	4.2	4.3	29.0
Pubescent birch, leaves	VII-6	4.4	7.6	7.0	46.8
id., whole crown	45.3 VII-6	2.5	4.2	3.5	42.4

flectance of old shoots with needles and to about 50 % of that of young shoots in the visible part of the spectrum. For the infrared region the corresponding figures are about 90 % and 75 %, respectively. Crowns of deciduous trees, including larch, reflect about 50 % of the visible light returned by single leaves or shoots with needles. In the infrared larch crowns reflect about 50 % and crowns of deciduous hardwood trees about 75 %, compared with the needle and leaf data. These are rather crude figures, however, and there may be large variations from one species to another. For coniferous trees the reflectance of crowns will also vary for one species according to the phenological aspect, i.e., to the ratio between the amount of young and that of old needles. In almost all

cases, the reflectance of whole crowns is considerably lower at all wavelengths than that of foliage measured separately. This is mainly the effect of shadows present within the crowns. The above results show that there is some shift of the ratio between the reflection of visible light and that of infrared radiation when going from the needle and leaf data to the crown data. Within the visible spectrum there is no significant change of color, although the spectral reflectance curves of crowns (see 11.1 and 23.1) show some tendency to be flatter in the red region, i.e., to have a less pronounced reflectance minimum, and to start the typical upswing at the upper end of the visible region earlier. This may be due to a certain influence of branch and perhaps even soil surfaces shining through the foliage. The data are not sufficiently numerous, however, to decide whether or not this is a consistent trend.

The reflectance of whole stands is still lower, because here not only the shadows in the crowns themselves but also shadow areas between the individual trees have an influence. Stands of coniferous trees as a whole reflect 40 - 60 % of the amount of visible light returned by old shoots and 20 - 40 % compared with young shoots. For hardwood stands the corresponding figure amounts to 30 - 50 %. In both cases the loss of infrared reflectance is somewhat smaller.

There is some indication that the blue component in the color of whole stands seen from the air becomes stronger than that in the actual foliage color as also illustrated by Diag. 40, where the spectral reflectances of a stand of spruce when measured on the ground (in a more or less horizontal direction) and from the air as reported by E. L. Krinov (KRINEL47SOS, English translation: KRINEL53SRP) are compared with each other. The relative increase of reflection intensity in the blue region is obviously caused by the shadows present within the forest stand and by some intervening haze light.

Changes of contrast between species when going from the foliage to the crown and stand data will be discussed in section 3.1.11 - 13.

Sources: ALEKVA60SDP, ARCYES58OSD, BELOSV59AFL.

3.1.8 Angular dependence of reflection of forest stands

We have already seen in the previous section that the reflectance of forest stands is very much governed by their structure. It is also clear that such rough surfaces do not have orthotropical properties. This means that the same stand will look brighter or darker depending on the angle of observation.

V.A.Alekseev, E.S.Arcybashev and S.V.Belov have investigated this angular dependence of reflectance by taking airborne measurements with aerial spectrographs (see section 1.4.1) and by comparing data obtained for the nadir direction with recordings at oblique directions, whereby the tilt of the spectrograph was 25 or 30°. These oblique measurements were at the following directions: 1. Away from the sun; 2. against the sun and 3. in a plane perpendicular to the cast shadow direction. The results are summarized seperately for the visible and the infrared spectral region, respectively, in Table 15. A selection of corresponding spectral reflectance curves is presented in Diags.: 25 - 30.

An analysis of these results leads, in conjunction with the description of measured stands in Tables 4 - 6, to the following conclusions:

1. The degree to which reflectance depends on the angle is governed primarily by the shape of the tree crowns (pointed, flat-topped, etc.), the surface of the crown canopy (flat, irregular) and the degree of crown closure. Pointed crowns give rise to a sharp contrast between illuminated and shady sides, whereas with flat-topped crowns this contrast is smaller and the transition more gradual.

A crown canopy with an irregular upper surface (varying tree heights) produces a mosaic of lights and shadows, so that a stand has a tendency to look relatively dark when seen vertically from above or from a position opposite to the sun. On the other hand, a flat regular canopy will produce lesser differences between various directions of observation.

Similarly, in a forest stand with a relatively low crown closure, heavily shaded interspaces will exist between trees. In this case the reflectance vertically downwards will be clearly the lowest, at least with a relatively high solar altitude, since these shadow areas, being on the ground, will be obscured for oblique angles of observation. Forest stands with flattopped tree crowns, a regular flat crown canopy and a high crown closure will have the closest approximation to an orthotropical reflection pattern.

2. The sun's altitude, of course, also has an influence. With low sun contrasts between different angles of observation will increase. As an example, see the data of the Tomsk area in Table 15. Here, although all stands have relatively low crown closures, the lowest values were recorded for the oblique observations against the sun, not for the vertical ones.

3. A forest stand always looks brightest when seen in a direction parallel or similar to that of the incident light, i.e. with the sun behind the observer, because then the illuminated parts of trees dominate.

Table 15 Angular dependence of reflection from forest stands (based on data reported in ALEKVA60SDP, ARCYES580SD and BELOSV59AFL)

SRC = Spectral reflectance curve
DM = Direction of measurement: The first figure indicates the angle of tilt of the measuring instrument, the second one the azimuth.
Thus:
DM 0 = vertical   DM x, 90 = transverse to direction of incident light
DM x,0 = against the sun   DM x,180 = with the sun behind the observer
Values in parentheses = percent of DM 30,180
SA = Solar altitude

	No.	Type of stand	Crown closure	Reflectance in %								SRC no.
				Visible region				Infrared region				
				DM 0	DM 30, 180	DM 30, 0	DM 30, 90	DM 0	DM 30, 180	DM 30, 0	DM 30, 90	
				550 - 690 mμ				710 - 750 mμ				
L'vov VII-11, SA 54°	1	Scotch pine (plot 1 in Table 6)	1.0	2.5 (74)	3.7 (100)	1.8 (53)		24.3 (89)	27.4 (100)	19.1 (70)	-	25.2/25.1 25.3/ -
	2	Scotch pine (plot 5)	0.9	2.7 (90)	3.0	2.2 (73)	-	22.9 (77)	29.8	21.8 (73)	-	
	3	European white birch(plot 3)	0.9	2.9 (67)	4.3	2.4 (56)	-	46.4 (84)	55.0	37.4 (68)	-	28.2/28.1 28.3/ -
	4	Beech (plot 6)	0.9	4.8 (72)	6.7	5.2 (78)	-	48.7 (89)	54.6	43.0 (79)	-	29.2/29.1 29.3/ -
	5	European alder (plot 7)	0.8	4.7 (87)	5.4	3.4 (63)	-	46.0 (90)	50.9	37.1 (73)	-	

Table 15 (Continued)

	No.	Type of stand	Crown closure	Reflectance in %								SRC r.o.
				Visible region				Infrared region				
				DM 0	DM 30, 180	DM 30, 0	DM 30, 90	DM 0	DM 30, 180	DM 30, 0	DM 30, 90	
Leningrad, VIII-11; SA 36-32°				530 - 690 mμ				710 - 770 mμ				
	6	Scotch pine (plot 1 in Table 4)	0.7	5.6 (79)	7.1 (100)	6.3 (89)	5.9 (83)	15.5 (80)	19.4 (100)	17.0 (88)	15.7 (81)	26.1/ - 26.2/26.3
	7	European white birch (plot 3)	0.85	6.3 (100)	6.3	5.3 (84)	6.3 (100)	21.7 (89)	24.4	20.3 (83)	21.2 (87)	
	8	Aspen (plot 4)	0.7	5.0 (79)	6.3	5.4 (86)	4.6 (73)	23.2 (72)	32.4	25.4 (78)	26.0 (80)	30.1/30.2 - /30.3
Tomsk, IX-12/15 SA 34-40°				550 - 690 mμ				710 - 790 mμ				
	9	Scotch pine (plot 1 in Table 5)	0.8	3.6 (54)	6.6	2.8 (42)	4.6 (70)	24.8 (86)	29.0	21.3 (73)	25.9 (89)	
	10	Scotch pine (plot 2)	0.6	4.9	-	4.1	3.5	34.1	-	31.6	33.3	
	11	Scotch pine (plot 3)	0.5	5.0 (57)	8.7	3.3 (38)	6.2 (71)	31.8 (78)	40.5	28.2 (70)	35.9 (89)	
	12	Siberian fir (plot 4)	0.65	2.3 (53)	4.3	1.5 (35)	2.6 (60)	24.1 (75)	32.0	19.8 (62)	26.2 (82)	27.3/27.2 - /27.1
*				430 - 690 mμ				710 - 790 mμ				
	13	Dead trees (plot 5)	0.6	4.6 (60)	7.6	3.4 (45)	5.2 (68)	17.9 (59)	30.3	12.5 (41)	23.9 (79)	36.3/36.2 - /36.1

* Tomsk. VII/VIII; SA 38-43°

The data observed at oblique angles in a plane perpendicular to the shadow direction are similar to those obtained for the vertical reflection, provided that the crown closure is relatively high. In both cases illuminated and shady parts of crowns are seen in about the same proportion. It is for this reason that the respective data have not been reported in detail by the Russian authors in the case of the L'vov area observations. For a low crown closure, however, the oblique transverse reflection values will usually exceed the vertical ones.

Each type of forest may have its specific properties with respect to the angular reflectance pattern. The following remarks refer primarily to the reflectance of visible light.

Pines have relatively round crown tops so that the contrasts between the different angles of observation tend to be rather low (see nos. 2 and 6 in Table 15). With high crown closure (no. 2) the vertical data are higher than the against-the-sun data. The opposite is true for a relatively low crown closure (no. 6) (see also Diag. 26). For pine stand no. 1 the angular dependence of reflectance is more pronounced, since it is, in contrast to no. 2, a stand of young trees with more pointed crowns and more irregular heights (see also spectral curves in Diag. 25). Stands nos. 9 - 11 have a low crown closure. Consequently, the values obtained for the nadir direction tend to be low. The against the sun values are still lower, however, which, as already mentioned above, may be explained by the relatively low altitude of the sun.[16)]

The crown shape of birches is similar to that of pines. Their stands are usually of the two story type and the crown canopy is irregular. Nevertheless, the shadow areas between the upper crowns and the shaded crown parts do not have a very heavy influence, since birch crowns are relatively transparent and shadows thus relatively weak (see nos. 3 and 7 in Table 15 and Diag. 28).

The rather flat tops of beeches cause the shaded crown parts to be small. Therefore, the shadow interspaces between trees have a greater influence, even with a high crown closure, and the reflectance vertically upwards is the lowest (no. 4 in Table 15, Diag. 29).

The aspen stand investigated in the Lisino area (no. 8) had an irregular crown canopy and a relatively low crown closure. As a result, the vertical value is lower than the against-the-sun value. Spectral curves are shown in Diag. 30.

Firs and spruces have pointed crowns, which leads, even with a high crown closure, to a heavier contrast between away-from-the-sun and against-the-sun observations than for other species (see no. 12 in Table 15 and spectral curves in Diag. 27). By the same token the oblique reflectance away from the

sun is lower than that vertically upward.

No. 13 in Table 15 and Diag. 36 represent data obtained over a stand of dead trees, predominantly firs. Their angular reflectance pattern is similar to that of living firs (no. 12).

With respect to infrared reflection most of the investigated stands showed a behavior similar to that concerning the visible light. In general, however, the angular dependance of reflectance tends to be somewhat smaller.

The shape of all spectral curves remains at all angles very much the same, i.e., color does not depend on the direction of observation. However, except for the measurements taken on the dead trees stand, the recordings did not cover the blue region of the spectrum, so that the question of whether or not there is a correlation between the amount of shadows and the intensity of the blue component cannot be answered.

Sources: ALEKVA60SDP, ARCYES58OSD, BELOSV59AFL.

3.1.9 Reflectance as a function of solar altitude

It is certain that the angular reflectance pattern of roughly structured cover types such as forests will be influenced by the altitude of the sun. Some respective remarks have already been made in the foregoing section. Most interesting, however, would be to know how much the vertical upward reflectance depends on solar altitude. For entire stands no data are available which would answer this question.

Measurements carried out on the ground on spruce needles suggest that the reflectance of the needle surfaces alone does not change significantly with a change of sun's altitude. In Diag. 38, Curve 1 was obtained at 28^{0}, 2 at 34^{0} and 3 at 40^{0} solar altitude. All curves are very close to each other or even overlap each other.

Even if objects under investigation do not change their reflectance as a function of the altitude of the sun, it is advisable to compare only results with each other which have been obtained under similar conditions of illumination. Standard surfaces used for reference, such as barite paper, do not behave exactly orthotropically. N.V.Eliseeva found that at an angle of incidence of 45^{0} the brightness of barite paper seen in the normal direction changed about 0.8 % per 1^{0} change of the incidence angle (reported by BELOSV59AFL). It is suggested that measurements are comparable if they have been taken within a change of

the sun's altitude of 5^{o}. Under these circumstances probable errors associated with this change do not exceed the errors caused by the measuring technique.

Source: BELOSV59AFL.

3.1.10 Reflectance of tree barks

In general, the reflectance of the bark of stems and branches does not have a significant influence on the integral aspect of trees seen from the air, unless the density of the foliage is rather sparse as is the case with trees growing on poor sites. It is, however, of importance for the winter aspect of deciduous trees and the appearance of dead trees.

Examples for the reflectance of stem bark and branches without leaves or needles are provided in Table 16 and Diags. 31 - 34. All spectral curves are either almost neutral (as bark of aspen, birch and Siberian fir) or exhibit a gradual and relatively slow increase from the blue end of the spectrum into the infrared (all others). Only the young stem bark of Scotch pine with its yellow-orange color (Curve 32.1) gives rise to a more pronounced upward trend of reflection from shorter to longer wavelengths. Old bark (Curve 32.2) has a much more brownish color and, therefore, there is less contrast between the red and the blue spectral region. The reflectance of barks is, in general, higher than that of leaves or needles, especially in the orange-red spectral region. The situation is reversed in the near infrared, however.

The highest reflectance of visible light can be observed for the smooth white bark of birch (81 %). This is followed by birch bark from the lower part of tree stems with fissures (32 - 33 %), aspen bark (25 %) Siberian fir bark (17 %), young bark of Scotch pine (13 %), old bark of Scotch pine (9 %) and beech bark (8 %).

Fresh pine branches without needles (Curve 31.2) reflect light similar to pine bark, whereas the reflectance of fresh leafless aspen branches is lower and less neutral than that of aspen stem bark. The reflectance of the dry branches of dead trees depends to some extent on the coverage by beard-moss. The spectral remission curve for the latter is shown in Diag. 34 (Curve 3). It is higher than that for tree branches. From the results shown in Table 16 and Diag. 34 it can be seen that there is some tendency toward an increase of reflection with an increase of the branch surface covered by beard-moss.

The reflectance of a whole stand of dead trees as measured from the air

Table 16 Reflectance of bark and branches of various tree species in selected spectral intervals (based on data reported in AHEKVA60SDP and BELOSV59AFL)

SRC = Spectral reflectance curve
* = Data incomplete for spectral interval specified

Object	Spectral region	Blue	Green	Red	Visible	Infrared	SRC no.
		Reflectance in %					
L ' v o v							
	Wavelength (mμ)	400–490	510–590	610–690	400–690	710–890	
Young bark of Scotch pine, yellow-orange		7.1*	11.1	19.1	13.2*	40.0	32.1
id., old, brown		6.4*	8.4	11.7	9.2*	23.6	32.2
Bark of birch, lower part of stem		30.5*	33.0	33.9	32.8*	38.2	
Bark of beech, dark gray		6.7*	8.7	9.3	8.5*	18.2	32.3
T o m s k							
Bark of birch, white, smooth		73.9	82.0	87.5	81.1		33.1
id., lower part of stem, with dark-gray fissures		29.8	32.4	33.5	31.9		33.2
Bark of aspen		22.3	25.4	27.8	25.2		31.1
Bark of Sib. fir, lower part of stem		15.4	16.8	18.1	16.8		33.3
Bark of Sib. stone pine, lower part of stem		9.8	11.4	13.1			
Fresh branches of Scotch pine, without needles		7.8	13.2	19.8	13.6		31.2
Fresh branches of aspen, without leaves		5.8	8.8	11.6	8.8		31.3
Dry branches of Norway spruce, 60% of surface covered by beard-moss		7.6*	10.3	14.7	11.1*	24.1*	34.1
id., fir, 70% beard-moss		7.4*	9.5	15.0	10.8*	26.2*	
id., Scotch pine, 10% beard-moss		-	9.2	13.4	11.5*	23.1*	
id., Sib. stone pine, 5% beard-moss		7.0*	8.4	12.0	9.3*	21.9*	34.2
Beard-moss, air-dry		11.9*	16.0	15.1	14.5*	20.4*	34.3
Stand of dead trees, measured from the air (plot 5 in Table 5)		3.9*	4.5	5.2	4.6*	17.9*	

is shown in Diag. 36. The curve for the vertical direction is not given. It would lie between curves 1 (measurement at a transverse direction) and 3 (measurement against the sun). Compared with the data for bark and branches it is surprising that the curves exhibit a sharp upswing at around 700 mμ. It must be assumed that this is the result of the underlying vegetation covering the ground. Also, the average reflectance of visible light of the whole stand is much lower (5 %) than that of single dry branches (20 - 26 %).

Sources: ALEKVA60SDP, BELOSV59AFL

3.1.11 Comparison of species on the basis of ground measurements of foliage

After having discussed the various factors governing the reflectance of trees we now turn our attention to a direct comparison of different species. It should always be kept in mind, however, that reflectance is variable as a result of the factors mentioned above and that only data obtained under similar conditions may be compared.

In Table 17 some foliage reflectance data are compared which were obtained in the Leningrad and the L'vov area at different seasons. Corresponding spectral reflectance curves are refered to in this table. The first series of measurements was conducted on June 21 in the Leningrad area, i.e., at a time of early summer aspect of trees. Birch leaves at this time were full sized, but had still a light-green color. The leaves of aspen were developed to about 2/3 of their final size. Consequently, the foliage of these deciduous trees reflects relatively strongly in the visible spectrum (7 - 7½ %). One should note, however, that the visible light reflectance of young pine and spruce needles is similar or even higher (9 - 10 %), especially in the red portion of the spectrum. Spruce needles at this time had a length of 10 - 11 mm and their color was light-green. Pine shoots were still partly covered by brown scales. The reflectance of old needles, on the other hand, is low (2½ - 3½ %). Of course, the apperance of coniferous trees as seen from the air is determined by the ratio between young and old needles. It is, therefore, difficult to draw conclusions from foliage measurements and much more reliable data can be collected by measuring whole crowns or stands (see sections 3.1.12 and 3.1.13).

Similar results were obtained on June 7 and 8 in the L'vov area, although here the reflectance of all species is consistently higher than in the Leningrad area, for the reason discussed earlier (see section 3.1.6). In the L'vov area

Table 17 Comparative table for the reflectance of foliage of various tree species in selected spectral intervals (based on data reported in ALEKVA60SDP and ARCYES580SD)

SRC = Spectral reflectance curve

Object / Spectral region	Blue	Green	Red	Visible	Infrared	SRC no.
Leningrad area				Date:	VI-21	
Wavelength (mμ)	430-490	510-590	610-670	430-670		
Scotch pine, young needles	6.6	12.0	12.0	10.4		
id., old needles	2.3	4.6	3.4	3.5		
Norway spruce, young needles	4.0	13.6	8.6	9.0		13.1
id., old needles	1.5	3.6	2.4	2.6		13.3
Birch, young leaves	3.7	10.9	6.6	7.4		13.2
Aspen, young leaves	2.9	11.0	6.7	7.2		
				Date:	IX-9	
Wavelength (mμ)	450-490	510-590	610-690	430-690		
Scotch pine	1.2	2.4	1.9	1.9		56.1
Norway spruce	1.0	1.8	1.5	1.5		
Birch	2.0	3.4	2.5	2.8		56.2
Aspen	2.7	4.8	2.9	3.6		56.3
				Date:	X-8	
Scotch pine	2.4	5.1	3.7	4.0		57.3
Norway spruce	2.0	3.7	2.8	3.0		
Birch (yellow)	5.4	19.8	27.9	19.6		57.1
Aspen (yellow)	3.4	15.9	25.2	16.6		57.2
L'vov area				Date:	VI-7/8	
Wavelength (mμ)	450-490	510-590	610-690	450-690	710-890	
Scotch pine, old needles	5.4	7.6	6.3	6.6	33.0	2.1
Norway spruce, young needles	7.7	13.2	12.5	11.7	53.0	4.1
id., old needles	4.6	6.8	6.2	6.0	29.5	5.1
Sycamore maple	7.8	10.3	9.0	9.2	76.0	
Ash	7.5	10.2	7.3	8.5	70.0	50.2
English oak	6.3	15.0	9.7	10.9	71.9	50.3

Table 37 (Continued)

Object / Spectral region	Reflectance in % Blue	Green	Red	Visible	Infrared	SRC no.
L ' v o v a r e a (Continued) Date: VI-17/20						
Wavelength (mμ)	430-490	510-590	610-690	450-690	710-890	
Scotch pine, young needles	7.8	12.9	11.7	11.3	59.1	1.1
id., old needles	4.4	5.9	5.7	5.5	28.6	2.2
Norway spruce, young needles	7.0	11.6	10.8	10.2	59.5	
id., old needles	3.7	5.5	4.9	4.8	27.3	
Europ. white birch	8.9	14.8	14.0	13.1	76.6	50.1
Date: VII-15/16						
Scotch pine, young needles	4.3	8.0	7.0	6.7	49.6	
id., old needles	3.5	5.3	4.1	4.4	25.1	2.3
Norway spruce, young needles	5.1	10.4	8.6	8.5	56.5	
Beech	5.8	10.2	7.9	8.3	76.0	16.1
Aspen	7.1	11.7	8.9	9.6	75.4	
Sycamore maple	6.2	9.8	7.3	8.0	63.0	
Pedunculate oak	5.2	8.9	6.5	7.1	61.8	
Date: VII-31/VIII-1						
Scotch pine, young needles	4.0	7.0	6.1	6.0	43.0	1.2
id., old needles	3.2	4.9	4.9	4.5	24.5	46.1
Norway spruce, young needles	4.4	9.6	9.2	8.5	54.3	4.2
id., old needles	2.5	4.7	4.6	4.1	25.8	5.2
European white birch	6.0	9.8	9.2	8.7	61.7	46.2
Beech	3.0	7.1	6.0	5.7	68.7	16.2
Aspen	4.4	7.9	7.0	6.8	55.5	47.2
Sycamore maple	4.7	7.1	5.7	6.0	62.1	
Ash	2.9	6.9	4.8	5.2	56.9	47.3

Table 17 (Continued)

Object / Spectral region	Reflectance in %					SRC no.
	Blue	Green	Red	Visible	Infrared	
L ' v o v a r e a (Continued)				Date:	IX-14/15	
Wavelength (mμ)	450-490	510-590	610-690	450-690	710-890	
Scotch pine, young needles	3.2	5.2	3.4	4.1	34.2	
id., old needles	2.3	3.9	3.0	3.2	19.3	
Norway spruce, young needles	3.3	5.5	4.4	4.6	41.2	
id., old needles	1.9	3.6	3.2	3.0	23.9	
European white birch	7.7	12.2	9.8	10.2	57.0	
Beech	4.3	8.2	6.5	6.6	60.7	16.3
Aspen	5.0	8.9	6.6	7.1	51.6	
Sycamore maple	4.8	7.4	5.9	6.2	56.3	
Ash	3.9	5.9	4.5	4.9	53.5	
				Date:	IX-29/30	
Norway spruce, young needles	2.7	5.1	4.6	4.3	40.4	4.3
id., old needles	1.2	2.8	2.6	2.4	20.7	5.3
European white birch	4.3	8.7	6.6	6.8	35.6	18.2
Beech	3.0	6.2	4.6	4.8	36.9	17.1
Aspen (yellow)	5.2	10.9	7.4	8.2	47.0	
Sycamore maple	3.9	7.1	5.3	5.6	52.6	
Ash	3.5	11.4	7.4	8.0	50.0	
Pedunculate oak	5.4	8.1	6.0	6.7	51.0	
				Date:	X-11/12	
Scotch pine, young needles	4.8	7.6	4.4	5.7	35.6	1.3
id., old needles	2.8	4.4	3.3	3.6	18.7	48.1
European white birch (yellow)	9.3	30.5	43.6	30.6	55.5	18.3/ 48.2
Aspen (yellow)	5.6	22.3	30.0	21.4	47.8	49.2
Sycamore maple(yellow)	6.1	19.6	27.1	19.4	47.9	
Ash (yellow)	5.7	17.8	11.6	12.6	53.3	49.3
Beech (dry, gray-brown)	-	5.0	10.2	7.6	21.0	17.3
Aspen (dry, gray)	6.9	8.4	11.1	9.1	16.8	

measurements in the near infrared were also taken, and it can be concluded that, in contrast to the situation within the visible spectral interval, young leaves reflect more radiation than young needles.

The further development throughout the summer can be inferred from the data collected at several seasonal intervals in the L'vov area. Corresponding spectral reflectance curves, as far as reproduced in this report, are referred to in Table 17. Birch leaves have consistently the highest reflectance in the visible (9 - 13 %) and reflect also heavily in the near infrared spectrum (57 - 77 %). The other deciduous species have a lower reflectance and are rather similar to each other (5 - 10 % in the visible, 54 - 57 % in the infrared part of the spectrum) with the exception of beech, which has a tendency to reflect more infrared radiation, even more than birch (61 - 76 %). The data also illustrate the well-known fact that, for the summer aspect of trees, the contrast between coniferous and hardwood species is greater in the infrared (about 1 : 1.7) than in the visible region (about 1 : 1.4), if one assumes that the integral reflectance of whole coniferous trees lies somewhere between that of young and that of old needles. Contrasts between deciduous species are greater in the visible spectrum, especially in the blue and the red spectral bands. As an example, the reflectance of the foliage of some trees as measured on July 31/ August 1 has been calculated relative to that of ash leaves in Table 18. The contrast between Scotch pine and Norway spruce is but low throughout the whole spectrum.

For the time of fall coloration it is again difficult to draw reliable conclusions from reflectance data obtained on leaves, since at a given time, a tree may have leaves with different colors. It can be seen, however, that the contrast between hardwood and coniferous foliage is now pronounced throughout the whole spectrum. It is especially high in the red spectral band (varying between 3 : 1 and 10 : 1). It drops again as soon as the leaves have completely withered.

Data obtained in the Leningrad area in fall before and after the beginning of leaf coloration confirm what has been stated above regarding the contrast between deciduous and coniferous foliage, at least for the visible spectral region. In the near infrared no measurements were taken.

Sources: ALEKVA60SDP, ARCYES58OSD.

Table 18 Relative reflectances of deciduous foliage as measured on July 31 / August 1 in the L'vov area (based on data reported in ALEKVA60SDP)

Species	Relative reflectance (ash = 1.0)				
Spectral region	Blue	Green	Red	Visible	Infrared
Wavelength (mμ)	450-490	510-590	610-690	450-690	710-890
Birch	2.1	1.4	1.9	1.7	1.1
Aspen	1.0	1.0	1.3	1.3	1.2
Sycamore maple	1.5	1.1	1.4	1.2	1.0
Beech	1.6	1.0	1.2	1.1	1.1
Ash	1.0	1.0	1.0	1.0	1.0

3.1.12 Comparison of species on the basis of whole crowns

S.V. Belov et al. carried out a number of reflectance measurements on whole crowns from a tower (for method of measurement see section 1.6.2) in both the Arkhangelsk and the Tomsk area. At the time of the first series of recordings in the Arkhangelsk area (July 3 - 7) the phenological stage of the vegetation was as follows: The deciduous hardwood species (pubescent birch and aspen) had fully-developed foliage. Norway spruces had young shoots 3 - 6 cm long with light-green needles 13 - 18 mm in length and older shoots 4 - 10 cm long with dark-green needles 13 - 21 mm in length; the young shoots covered about 50 % of the crown projection. The corresponding data for the Scotch pines were: Young shoots 15 - 30 mm with light-green needles 25 - 31 mm; last year's shoots 3 - 9 cm with gray-green needles 32 - 67 mm; young shoots covering approximately 15 % of the crown projection. At the time of the later measurements on August 7 - 20, the trees had a typical late summer aspect, i.e., about 15 days later the deciduous hardwood species started to change their color. For the Tomsk area the authors do not give a detailed description of the aspect of the vegetation at the time of measurement.

A summary of the data is provided in Table 19 and spectral curves are represented in Diags. 43 - 45 and 53. The following conclusions can be drawn.

1. The reflectance of whole trees is always lower that that of needles or leaves as discussed earlier.

2. The various species have a rather similar reflectance within the visible part of the spectrum. However, there is some tendency for aspen and birch to

Table 19 Comparative table for the reflectance of whole crowns of various tree species in selected spectral intervals (based on data reported in BELOSV59AFL)

SRC = Spectral reflectance curve
* = Data incomplete for spectral interval specified

Object	Reflectance in %					SRC no.
Spectral region	Blue	Green	Red	Visible	Infrared	
Arkhangelsk area				Date:	VII-3/7	
Wavelength (mμ)	430-490	510-590	610-690	430-690	710-790	
Norway spruce	2.1	3.7	2.9	3.0	18.9	43.1
id.	1.6	3.2	2.6	2.5	14.9	45.1
Scotch pine	2.1	3.7	3.2	3.1	22.3	
Pubescent birch	2.5	4.2	3.5	3.5	42.4	45.3
Aspen	2.5	4.7	2.6	3.4	25.5	
				Date:	VIII-7/20	
Scotch pine	2.8	5.4	-	4.2*	-	45.2
Siberian larch	2.3	4.9	3.8	3.8	17.0	43.2
Aspen	2.8	4.2	4.3	3.8	29.0	43.3
Tomsk area				Date:	VIII-3/12	
Wavelength (mμ)	410-490	510-590	610-690	410-690	710-790	
Scotch pine	2.4	5.0	5.0	4.1	41.6	53.2
Siberian stone pine	2.3	4.5	3.9	3.6	41.6	44.2
Siberian spruce	2.1	4.2	3.5	3.2	37.2	53.1
Siberian fir	2.0	3.8	4.2	3.3	40.4	44.1
Birch	3.1	5.1	5.8	4.7	51.7	53.3
Aspen	3.4	5.5	4.7	4.6	51.7	44.3

reflect more than coniferous trees at the blue end of the spectrum. Also, the curves for spruce are clearly the lowest in the red spectral band. The contrast between the group of hardwood trees and that of softwood trees is smaller (about 1.2 : 1) than that between corresponding foliage.

3. A consistent contrast between the groups can, however, be observed in the near infrared, although it is also somewhat smaller than that between foliage (1.6 - 1.7 : 1 on the average).

Source: BELOSV59AFL.

3.1.13 Comparison of species on the basis of whole stands measured from the air

Results of airborne measurements carried out by E.S. Arcybashev, V.A. Alekseev and S.V. Belov over pure stands in the L'vov, Leningrad and Tomsk areas are given in Table 20 and Diags. 10, 55 and 58 - 60. The two groups of coniferous and deciduous trees overlap each other within the visible spectral region. Stands of Norway spruce have clearly the lowest reflectance: Scotch pine stands and birch stands have almost the same brightness, and aspen stands reflect even less than Scotch pines. This is just the opposite to the data shown in Diag. 56, which are based on ground measurements of leaves. The aspen stand measured had a rather small crown closure, so that shadows between the trees affect the reflectance. According to the Russian authors, however, this situation is not typical for aspen stands in general.

Birch forest has a lower visible brightness than beech forest. This result is in contrast with observations made on the ground (see section 3.1.11). There birch leaves reflect more than beech leaves. As in the case of pines and aspens above, an explanation for the reversal of the contrast has to be sought in the structure of the crown canopies. Beech crowns have flat tops and their closure is high. Consequently, the influence of shadows is small. Birch crowns, on the other hand, are irregular. Also, birches usually grow in two stories and the closure of the overstory is incomplete. As a result, there are numerous shadow areas between the crowns.

A clear separation between the coniferous and the deciduous stands can be obtained in the infrared only, where contrasts vary between 1 : 1.4 and 1 . 2. Within groups, however, differences are very small. It should be noted that the last series of measurements in the Leningrad area was obtained with an aerial spectrograph (see section 1.4.1), the earlier ones with a Universal Photometer (see section 1.2.1). This change of the instrument probably explains the large difference in general height of reflectance between the July 19 and the August 11 data.

Sources: ALEKVA60SDP, ARCYES58OSD, BELOSV59AFL.

3.2 Spectral reflectance of forest clearings and bogs

A few data on the reflectance of forest clearings and bogs obtained from the air have been reported by V.A. Alekseev, E.S. Arcybshev and S.V. Belov.

Table 20 Comparative table for the reflectance of whole forest stands measured from the air (based on data reported in ALEKVA60SDP, ARCYES58OSD and BELCSV59AFL)

SRC = Spectral reflectance curve
* = Data incomplete for spectral interval specified

Object: Stand	Reflectance in %					SRC no.
Spectral region	Blue	Green	Red	Visible	Infrared	
L ' v o v a r e a				Date:	VII-11	
Wavelength (mμ)		550-590	610-690	550-690	720-750	
Scotch pine (plot 5 in Table 6)		3.7	2.1	2.7	22.9	10.2
Birch (plot 3 in Table 6)		3.8	2.4	2.3	46.4	55.1
Beech (plot 6 in Table 6)		6.3	3.8	4.8	48.7	55.2
Alder (plot 7 in Table 6)		6.2	3.7	4.7	46.0	55.3
L e n i n g r a d a r e a				Date:	VI-24	
Wavelength (mμ)	450-490	510-590	610-690	450-690	710-770	
Scotch pine	2.1	3.6	2.3*	2.8*	-	58.1
Norway spruce	1.2	1.7	1.4*	1.5*	-	58.3
Birch	2.0	3.7	2.2*	2.8*	-	58.2
				Date:	VII-19	
Scotch pine	1.8	2.8	2.0	2.2	-	59.1
Birch	1.4	2.6	2.2	2.2	-	59.2
Aspen	1.2	1.9	1.6	1.6	-	59.3
				Date:	VIII-11	
Scotch pine	-	6.1*	5.2	5.6	15.9	60.1
Norway spruce	-	3.6*	3.4	3.5	13.4	
Birch	-	6.9*	5.5	6.1	20.5	60.2
Aspen	-	5.3*	4.7	4.9	21.8	60.3
T o m s k a r e a				Date:	X-14	
Wavelength (mμ)		550-590	610-690	550-690	710-790	
Scotch pine		5.0	3.1	3.8	34.0	
Siberian fir		6.5	5.3	5.8	36.0	
				Date:	VIII-25	
Birch		6.7	4.7	5.4	49.6	
Aspen		-	4.3*	-	50.2	

Curves 35.2 and 35.3 represent the spectral reflectance of a clearing covered by young growth and from one without young growth, but covered by grasses, herbs, mosses and dwarf-shrubs. Both have spectral characteristics which are similar to those of meadows (see section 3.4), except for the infrared region, where the remission is lower (see also nos. 1 and 2 in Table 21). For the former, which is covered by young trees, predominantly birches and aspens having a height of 1.3 and a density of 0.6, the chlorophyll absorption in the red band seems to be somewhat stronger.

Table 21 Reflectance of forest clearings and bogs in selected spectral intervals (based on data reported in ALEKVA60SDP, ARCYES580SD and BELOSV59AFL)

SRC = Spectral reflectance curve
* = Data incomplete for spectral interval specified

No.	Object		Reflectance in %				SRC no.
		Spectral region	Green	Red	Visible	Infrared	
		Wavelength (mμ)	550-590	610-690	550-690	710-790	
1	Clearing with young growth (Leningrad, VIII-9)		7.0*	6.1	6.4*	21.8*	35.2
2	id., without young growth		6.6*	6.5	6.5*	25.5*	35.3
3	Peat digging area (Leningrad, VIII-9)		6.6*	7.9	7.6*	11.8*	65.1
4	Peat-moss bog (Tomsk, IX-10)		13.5	10.8	11.8	41.3	65.2
5	Peat-moss sedge bog (Tomsk, VII-8)		6.8	3.7	4.9	61.1	65.3
6	Low moor with sedges, moist (L'vov, VII-11)		7.3	5.6	6.3	39.2*	66.1
7	id., wet		4.7	3.6	4.0	24.3*	66.2

The reflectance curve obtained over a reddish-gray peat digging area (see Curve 65.1 and no. 3 in Table 21) shows a gradual upward trend from the visible to the infrared wavelengths and is similar to the data for peat soil reported by J.S.Tolchel'nikov (Curve 113.1). The spectral characteristics of a peat-moss sedge bog (see no. 5 in Table 21 and Curve 65.3) are comparable with those of meadows (for example, Curve 62.3). The reflectance of a pure peat-moss bog differs in that it is higher in the visible and lower in the infrared region (see

no. 4 in Table 21 and Curve 65.2).

Curves 66.1 and 2 show the spectral reflectance of a moist and a wet low moor with sedges. The difference in moisture explains the difference of general reflection intensity between the two, the wetter moor absorbing considerably more radiation. The infrared reflectance of low moors is significantly lower than that of high moors (see also no. 6 and 7 in Table 21).

Sources: ALEKVA60SDP, ARCYES58OSD, BELOSV59AFL.

3.3 Spectral reflectance of mosses and lichens

Reflectance data for mosses and lichens are scanty. In Diag. 54 two curves are shown which are based on measurements obtained by Z. L. Petrushkina in western Yakutia (reported in BAKHVM60MSA). Curve 1 represents the spectral reflectance of a brown moss species, Curve 2 that of reindeer moss. As would be expected, the first has a higher intensity in the yellow and red bands than in the green, whereas the second with its light-gray color is almost neutral in reflectance within the visible spectrum. In the near infrared region the contrast between the two is smaller than in the visible one.

The reflectance of beard-moss has been discussed in conjunction with that of dead trees (see section 3.1.10) and the influence of a lichen cover on the reflectance of rocks will be shown in section 5.1.

Source: BAKHVM60MSA.

3.4 Spectral reflectance of agricultural crops

The aspect of most agricultural crops undergoes pronounced seasonal changes. The spectral reflectance of green crops and meadows shows the characteristics which are typical for green vegetation, i.e., a maximum in the green spectral region and a sharp upswing at the lower end of the near infrared (see nos. 1,3,6,9 and 13 - 15 in Table 22 and Curves 39.1, 61.1, 62.1 - 3 and 63.1).

The ripening of grains manifests itself through an increase of reflectance in the yellow-red spectral zone and a drop in the infrared (see nos. 4 and 5 in Table 22 and Curves 61.2 and 61.3).

Table 22 Reflectance of meadows and agricultural crops in selected spectral intervals (based on data reported in ALEKVA60SDP, ARCYBS58OSD, ARCYBS62ISJ and BELOSV59AFL)

SRC = Spectral reflectance curve
* = Data incomplete for spectral interval specified

No.	Type of crop	Reflectance in %					SRC no.
	Spectral region	Blue	Green	Red	Visible	Infrared	
	Ground measurements						
	Wavelength (mμ)	450-490	510-590	610-690	450-690	710-890	
1	Oats with vetch (L'vov, VIII-11)	4.7	8.2	5.5	6.4	42.1	39.1
2	id., stubble-field	3.7	7.4	7.1	6.4	26.5	39.2
3	Oats, flowering (L'vov, VIII-11)	4.2	8.2	5.7	6.3	43.8	61.1
4	Rye, ripe (L'vov, VIII-11)	8.7	13.9	16.0	13.5	30.1	61.2
5	Rye straw	7.2	11.9	17.1	12.8	26.8	61.3
6	Moist meadow with sedges and grasses (L'vov, III-5)	2.3	5.8	4.3	4.4	31.8	
7	Moist meadow with cut vegetation (L'vov, IX-8)	3.0	6.0	7.7	6.0	33.4	
8	Hay, gray-green (L'vov, IX-29)	5.7	8.3	8.5	7.8	34.7	
	Wavelength (mμ)	400-490	510-590	610-690	400-690	710-790	
9	Meadow with grasses, clover and crowfoot (Tomsk, VIII-31)	6.0	9.9	7.0	7.6	58.4	63.1
10	id., freshly cut (Tomsk, VIII-31)	7.8*	12.7	12.3	11.4*	48.3	63.2
11	Hay, dry (Tomsk)	-	12.0*	19.2	16.0*	38.3	63.3
12	Sod (Tomsk, cut on VII-2, measured on IX-8)	7.6	13.5	21.4	14.2	41.9	

Table 22 (Continued)

No.	Type of crop / Spectral region	Reflectance in %					SRC no.
	Spectral region	Blue	Green	Red	Visible	Infrared	
	Airborne measurement						
	Wavelength (mμ)	400-490	510-590	610-690	400-690	710-790	
13	Upland meadow (Leningrad, VIII-9)	-	9.0*	6.8	7.4*	28.5*	62.1
14	Rye, flowering (Tomsk, VII-5)	5.2	8.5	8.2	7.3	57.7	62.2
15	Meadow with grasses and broadleaved herbs(Tomsk, VII-8)	5.6	7.6	4.9	6.0	62.2	62.3
16	Cotton, before irrigation (Ashkhabad, VII)	-	31.6	41.9	36.8	58.0	67.1
17	id., after irrigation	-	26.0	30.5	28.2	34.4	67.2
18	Vineyard (Ashkhabad, VII)	-	24.4	26.9	25.7	41.7	67.3

The cutting of meadows or green forage grains also gives rise to an increase of reflectance in the visible part of the spectrum and to a drop in the infrared. The reflectance minimum in the red band gets weaker but does not disappear completely (see no.s 2 and 10 in Table 22 and Curves 39.2 and 63.2). Hay, as long as it is green, has a reflectance which is similar to that of cut meadows (see nos. 7 and 8 in Table 22). After having dried out, hay reflects considerably more visible light, especially in the red part of the spectrum (see no. 11 in Table 22 and Curve 63.3). The influence of drying out is also demonstrated by the reflectance of a piece of sod which was cut on July 2 and measured on September 8 (see no. 12 in Table 22). Excess soil moisture lowers the reflectance in both the visible and the infrared spectral region (see no. 7 in Table 22 and Diag. 64 where an upland and a swampy meadow are compared). An influence of soil moisture may also be recognizable in dry areas where crops are irrigated. Curves 67.1 and 2 show the reflectance of a cotton field before and after irrigation (see also nos. 16 and 17 in Table 22). The reflectance after irrigation drops to about 75 % (before irrigation = 100 %) in the visible and to about 60 % in the infrared region.

If the vegetation does not cover the soil completely, the results of measurements constitute a mixed reflectance of plants and soil. According to V.A. Alekseev and S.V. Belov, the smoothing out of reflectance curves for stubble-fields (see Curve 39.2) is due to the influence of the soil shining through. Curve 39.3 represents the reflectance of the soil of the field in question. In the case of E.S. Arcybashev's airborne recordings of the reflectance of cotton and vines, such an influence also seems to be present. The curves (67.1 - 3) do not have a maximum in the green and a minimum in the red band. It is probable, however, that this is not only caused by the soil but also by a cover of dust which was found on the plants at the time of measurement.

Compared with forests, meadows and crops are a very homogeneous type of vegetational cover and shadows have only a minor influence on reflectance. Consequently, there should be no great difference between measurements made on the ground and measurements taken from the air. This may even be true if the former are performed on individual plant elements, such as leaves, except for cases where the soil is visible, as discussed above. Some change in spectral characteristics of crops measured from the air, may however, be caused by intervening blue haze light, as demonstrated by an example reported by E. L. Krinov (see Curves 41.1 and 2).

Sources: ALEKVA60SDP, ARCYES58OSD, ARCYES62ISJ, BELOSV59AFL, KRINEL47SOS, VINOAI55PAP.

3.5 Spectral reflectance of semi-desert and desert vegetation

The plants of the semi-desert and desert zone can, with respect to their reflectance characteristics, be broken down roughly into two groups:

1. Mesophytic plants, occurring in depressions over lenses of fresh groundwater. They are darker, have a greater amount of plant mass and cover the soil more densely than the plants of group 2.

2. Xerophytic and halophytic plants, growing on the upland between depressions or in depressions with saline groundwater underneath. They have a less saturated green color, their leaves are narrow or absent completely and they may be covered by salt precipitations.

As a result, there usually exists in any one area a good contrast between the two groups, the former having a relatively low (3½ - 7 %), the latter a relatively high visible light reflectance (6 - 13%). In most cases, the contrasts

are somewhat higher in the red spectral region (about 1 : 2) than in other parts of the visible spectrum (about 1 : 1.5 - 1.7).

Semi-desert and desert plant also undergo seasonal changes. During summer, the vegetation on the higher lying terrain (for a description of relief features of the semi-desert zone see section 2.6) dries out and becomes sparser. At the same time, the vegetational cover in fresh groundwater depressions is still dense and green. Later in the year, the meadow vegetation in the depressions may also turn its color and become less dense. Due to the reflectance of the bare soil, however, the contrast between depressions and upland is then rather enhanced than reduced. Although no reflectance measurements were carried out in fall, E.S. Arcybashev concludes that the season does not have a decisive influence on the separability of vegetation types except for wintertime. Spring and summer give better contrasts between the vegetation in depressions with fresh groundwater and that in depressions with saline groundwater, however.

For the infrared spectral region only a few data are available. Nothing can be said with respect to a comparison of the infrared reflectance of the two vegetation groups mentioned above. On the other hand, it can be concluded that contrasts between soils and vegetation are lower in the infrared (see examples in Diags. 107 and 108) than in the visible region, so that infrared air photography does not give good results. For a separation of vegetation and soils, E.S. Arcybshev again recommends the use of the red spectral band. In some cases, however, this may give excessive contrasts, as for sand areas, where the ratio between the brightness of bare sand in the red wavelengths and that of vegetation may be as high as 5 : 1. Under such circumstances the use of the green spectral region will give better results.

Due to the high consistency of reflective contrasts between mesophytic and xero- and halophytic vegetation, the vegetational cover is a very useful indicator for groundwater surveying. Also most soils, though having a higher general reflectance than vegetation, follow this pattern: Soils over fresh groundwater reflect less light than saline soils. An exception to the rule are sand deposits which have the highest reflectance of all investigated objects, but indicate the presence of fresh groundwater. Data on the reflectance of vegetation and soil types indicating either fresh or saline groundwater have been compiled for spectral intervals in Table 23. This table also contains references to corresponding spectral curves.

It should also be noted that, similarly to what has been said for trees (see section 3.1.11), reflectance measurements taken on single plant leaves or branches do not permit reliable predictions of air photographic tones. An example is provided by Diag. 42, where the first curve shows the spectral reflectance of

Table 23 Reflectance of some vegetation and soil types of the semi-desert zone, which have indicator value for groundwater surveying (based on data reported in ARCYBS61SBL and ARCYBS62ISJ)

SRC = Spectral reflectance curve
* = Data incomplete for spectral interval specified

Type of indicator		Reflectance in %				
	Spectral region	Blue	Green	Red	Visible	SRC no.
	Wavelength (mμ)	430-490	510-590	610-690	430-690	
A. Indicators of fresh groundwater						
Meadow chestnut soil		8.5	11.7	13.6*	11.3*	70.1
Crested wheat grass		3.9	5.8	7.5*	5.7*	70.2
Couch grass (probably quack grass)		3.0	4.9	7.8*	5.3*	70.3
Barkhan sand, top a		17.5	23.3	28.3	23.4	73.1
id., top b		13.8	20.5	26.6	20.8	
id., slope		10.0	15.8	18.5	15.1	
Stable cover sand		11.2	13.2	14.8	13.2	
Deflation basin with vegetation		7.2	8.6	9.4	8.5	
Reed		5.3	8.8	5.1	6.5	73.2
Camel's thorn		4.3	7.6	6.1	6.1	
Tamarisk		3.5	7.4	6.6	6.0	73.3
Ruderal herbs on flood plain		2.7	7.8	4.1	5.0	68.1
Couch grass association		1.7	5.0	3.5	3.5	68.2
Sand polyn		6.0	8.0	7.0	7.1	72.2
Woodweed and blue grass		5.4	7.5	6.1	6.4	75.2
Licorice		4.6	6.8	5.2	5.6	75.3
B. Indicators of saline groundwater						
Saline meadow-chestnut soil		12.4	15.8	19.0*	15.7*	71.1
Wormwood (probably black polyn)		6.6	10.3	12.2*	9.7*	71.2
Salt-tolerating couch grass		7.0	10.0	12.4*	9.8*	71.3
Bijurgun association		9.0	14.0	15.6	13.1	74.1
White polyn association		3.2	6.8	7.2	5.9	74.2
White polyn		7.4	10.3	9.2	9.1	
Old river bed		12.8	15.3	17.4	15.3	
Annual saltwort		10.1	14.4	14.8	13.3	75.1

branches of black saxaul, which were in full sunlight and covered the angular field of the measuring instrument completely. Curve 3 was obtained for a whole shrub. The latter curve is considerably lower, indicating the influence of the structure of the shrub (especially shadows) on its brightness.

The reflectance measurements reported above obviously have been taken on whole plants or groups of plants, although this is not said specifically by the Russian author. Due to the relatively low density of many individual plants and of the vegetational cover as a whole, the underlying soil surface will always affect the measurements to a lower or higher degree. This may explain the flatness of many spectral reflectance curves without the clear maximum and minima otherwise typical for vegetation (see especially Curves 70.2 and 3 and 71.2 and 3).

Sources: ARCYES61SEL, ARCYES62ISJ, LJALKS60IOP.

4. Results of measurements: Soils and road surfaces

In his book on the spectral reflectance of natural formations, E. L. Krinov made an attempt at classifying the formations in a number of categories according to their spectral characteristics. He suggested that all bare areas and soils could be grouped together because their spectral curves have one thing in common: They all show a gradual upward slant from the short wave end of the visible spectrum into the near infrared, whereby different types of surfaces differ among themselves in the height of the curve on the ordinate (reflectance axis) and in the slope of the curve. The latter may vary between practically zero (the curve then being more or less horizontal to the abscissa i.e., the wavelength axis) and very high steepness. The data presented here on soils and road surfaces are in agreement with Krinov's conclusion. The height and the slope of curves may be dependent on a variety of factors. These will be discussed in the following sections.

4.1 Spectral reflectance of soils

In a manner similar to the procedure in the part on vegetation, we shall first discuss results of analytical investigations, concerning, for example, the influence of soil moisture, soil texture, etc. on reflectance, and then report on studies dealing with a comparison of various soil types.

4.1.1 Reflectance as a function of soil texture

In order to assess the effects of soil texture on reflectance of visible light, J.S.Tolchel'nikov and L.N. Belonogova made investigations on a number of samples prepared by separating pure minerals in some grain size classes. The results of this research are presented in Table 24 (integral reflectance values) and Diags. 82 - 87 (spectral reflectance curves). In each diagram three curves are shown for one mineral, representing the following texture classes: 1. Particles smaller than 0.1 mm in diameter; 2. 0.25 - 0.5 mm, and 3. 1.0 - 3.0 mm. The minerals investigated are microcline (Diag. 82), quartz (Diag. 83), biotite (Diag. 84), muscovite (Diag. 85), garnet (Diag. 86) and epidote (Diag. 87).

It can be seen in all cases that a decrease of grain size results in an

Table 24 Visible light reflectance (%) of various granulometric fractions of some minerals (based on data reported in BELOIN59ZSJ and TOLCJS60PPT)

SRC = Spectral reflectance curve

Mineral	Fraction (mm)					SRC no.
	<0.1	0.1-0.25	0.25-0.5	0.5-1.0	1.0-3.0	
Microcline	71.3	61.2	53.7	-	44.9	82.1/ - 82.2/ - 82.3/
Quartz	93.1	85.4	74.4	69.6	61.7	83.1/ - 83.2/ - 83.3
Biotite	7.4	6.7	5.8	5.0	4.4	84.1/ - 84.2/ - 84.3
Muscovite	60.0	51.0	40.0	27.4	23.9	85.1/ - 85.2/ - 85.3
Garnet	19.7	11.6	6.6	4.9	2.4	86.1/ - 86.2/ - 86.3
Epidote	30.3	19.6	13.2	-	6.6	87.1/ - 87.2/ - 87.3

increase of reflectance. This increase is caused by heavier light scattering and lower extinction of light passing through the particles. Also, the area covered by microshadows occurring between particles under oblique illumination becomes smaller. This fact is in contrast to experiences made with air photographic tones. On air photos, finely textured soil materials usually have a darker tone than coarse soils. This, however, is the result of either a higher water retention or a higher content of organic matter or both in the former, i.e., differences in soil moisture (see section 4.1.2) and humus content (see section 4.1.3) in general overshadow differences in soil texture.

The shape of the spectral curves does not change very much from one grain size category to another. Quartz, biotite and muscovite have a neutral color (i.e., horizontal spectral curves) in all cases anyway. A slight change of color can be observed for microcline and epidote

Sources: BELOIN59ZSJ, TOLCJS60PPT, TOLCJS66DAP.

4.1.2 Reflectance as a function of soil moisture

For an investigation of the influence of soil moisture on reflectance, J.S.Tolchel'nikov prepared a series of samples with various degrees of moisture (for a description of the preparation of samples see section 1.6.1), using material from a number of different soil types common in northern Kazakhstan (compare with section 2.5).

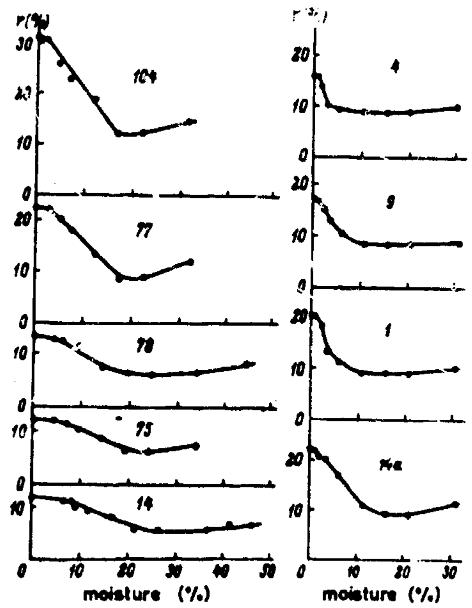


Fig. 35

Dependence of visible light reflectance on soil moisture content for a number of different soil types (from TOLCJS60PFT).
104 and 77 = Gley soloth, heavy loam, 78 and 75 = common chernozem, clay, 14 = humic gley soil, 4 = heavily podzolized sand, 9 and 1 = podzolized sandy loam, 14 a = podzolized light loam.

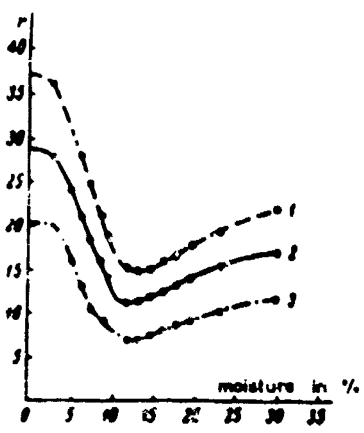


Fig. 36

Dependence of light reflectance on soil moisture for takyr soils (from BELOIN58NFI).
1 = 600 - 700 mμ, 2 = 400 - 700 mμ, 3 = 400 - 500 mμ.

Table 25 Analytic and reflectance data for soil samples used to determine the influence of humus, iron oxides and moisture on reflectance (from TOLCJS60PFT)

Sample No.	Granulometric composition (%)		Fe_2O_3 (%)	Humus (%)	Sum of Fe_2O_3+ Humus (%)	Moisture capacity (%)			Visible light reflectance (%) (air-dry)
	Fraction >0.01 mm	Fraction <0.01 mm				Hygroscopic	Maximum hygroscopic	Field capacity	
1	89.2	10.8	0.8	0.7	1.5	0.4	0.8	22.4	-
4	94.8	5.2	0.7	1.5	2.2	0.3	0.3	20.2	-
9	89.6	10.4	0.6	1.3	1.9	0.4	0.9	25.1	-
14	-	-	2.4	72.8	75.2	7.0	15.0	45.3	-
14a	79.5	20.5	0.6	0.6	1.2	2.1	5.1	21.5	-
69	42.7	57.3	4.2	0.4	4.6	3.9	-	-	20.4
70	28.4	71.6	4.2	1.1	5.4	3.8	-	-	20.8
71	31.5	68.5	4.5	4.0	8.5	4.1	-	-	11.0
72	39.5	60.5	4.1	0.6	4.6	3.8	-	-	19.8
73	31.1	68.9	4.3	1.6	5.9	4.0	-	-	16.5
74	31.3	68.7	5.0	2.3	7.3	4.5	-	-	12.3
75	28.3	71.7	5.5	2.6	8.1	4.5	11.4	35.5	11.9
76	31.6	68.4	4.5	8.2	12.7	4.6	-	-	9.1
77	48.7	51.3	3.6	1.4	5.0	2.7	5.4	22.5	21.7
78	31.1	68.9	5.3	1.6	6.9	4.6	11.7	39.0	12.6
79	33.6	66.4	5.2	1.3	6.5	5.4	-	-	14.9
80	36.7	63.3	5.3	1.6	6.9	5.7	-	-	13.2
90	25.2	74.8	5.3	4.1	9.5	6.0	-	-	9.5
91a	34.9	65.1	5.5	7.3	12.8	5.8	-	-	9.0
100	-	-	50.0	50.0	100.0	-	-	-	6.0
104	25.6	74.4	5.3	1.0	6.3	5.0	-	-	14.7[17]
105	45.8	54.2	2.9	1.1	4.0	2.2	5.5	31.5	31.5
150	48.5	51.5	0.0	0.0	0.0	-	-	-	58.0
158	27.7	72.3	5.0	3.5	8.5	4.1	-	-	12.8
163	34.2	65.8	5.1	6.2	11.3	4.4	-	-	9.8
544	19.8	80.2	6.2	0.3	6.5	4.4	-	-	14.1

The results of the determination of visible light reflectance as a function of moisture content are shown for ten different soil types in Fig. 35 and 36. Data describing the granulometric and chemical composition as well as the moisture capacity of soil samples are provided in Table 25. The following conclusions can be drawn:

1. Completely air dry soils have the highest reflectances. The height of this maximum depends on the type of soil, however.

2. Until the hygroscopic moisture content (see values in Table 25) is reached there is almost no change of reflection intensity.

3. Adding more moisture results in a heavy decrease of reflectance, especially between the state of maximum hygroscopic moisture and that of double this amount. Within this interval the decrease is approximately inversely proportional to the increase of moisture content. It is caused by the water which surrounds the soil particles to an increasing extent and absorbs light.

4. The location of this interval of greatest change of brightness with respect to the moisture axis depends on the type of soil. For sandy loams this change occurs between 0.3 and 2 - 3 %, for light clay loams between 2.0 - 2.5 and 11 - 12 %, for clays between 4 - 5 and 20 - 25 % and for humic gley soils between 7 and 30 % moisture.

5. The size of change also depends on soil type. The decrease of brightness is greatest for dark soils, i.e., soils having a high humus content. For example, the reflectance of the gley-soloth soil no. 104 (see Fig. 35) dropped from 31 to 12 % between 0 and 17 % moisture. For sample no. 75, which is a common clayey chernozem, the corresponding drop is from 12 to 5 % only.

6. If the water content of soils exceeds field capacity reflectance becomes more intensive again. The soils are now covered by a thin film of water which gives rise to a certain amount of specular reflection.

In order to investigate whether or not the color of soils is affected by a change of moisture, V. L. Andronikov, I. N. Belonogova and J. S. Tolchel'nikov conducted a number of spectral measurements on soil samples from various areas of the forest steppe, the steppe and the desert zone. In Diags. 88 - 92 spectral reflectance curves are shown for a common chernozem, a chestnut soil, a takyr soil[18], a light-gray forest soil, and a podzolized chernozem, each at three different states of moisture. Except for a slight tendency of the yellow-red component to become more pronounced relative to the remainder of the spectrum, the shape of the curves does not change with an alteration of the moisture content. It can be concluded that the color of soils is not influenced significantly by a variation of moisture. For a comparison, see also Fig. 36, where the change of in-

tegral reflectance as a function of moisture content has been plotted not only for the visible spectrum as a whole, but also for the 400 - 500 mμ and the 600 - 700 mμ spectral intervals.

Two further examples for the influence of moisture on reflectance are provided by Diag. 81 (yellow sand, wet and dry) and Diag. 93 (fallow field, dry, moist after harrowing and wet after rainfall). In contrast to the previous data, these latter results were obtained under natural conditions by taking measurement on the ground and from the air, respectively.

Sources: ALEKVA60SDP, ANDRVL58SPL, BELOIN58NFI, BELOSV59AFL, TOLCJS60PFT, TOLCJS66DAP.

4.1.3 Reflectance as a function of humus and iron oxide content

J.S.Tolchel'nikov, in his systematic studies on the reflectance of soils, also investigated the influence of humus and iron oxide content. In order to analyze the parts played by the individual components, he measured the spectral reflectance of extractions of humic and fulvic acid and of pure samples of hematite (Fe_2O_3) and magnetite (Fe_3O_4). The spectral reflectance of humic acid (Curve 2 in Diag. 77) is characterized by a low intensity throughout the whole visible spectrum and color neutrality, as can be seen from the horizontal course of the curve. The properties of fulvic acid (Curve 77.1) are different. Its reflectance increases from about 6 % at the blue end to about 21 % at the red end of the spectrum.

The spectral characteristics of iron oxides depend very much on the degree of oxidation and hydration of the iron ions. Magnetite (Fe_3O_4), being a mixture of bivalent and trivalent iron, is black with a slight blue-green tint as can be seen from the shape of Curve 2 in Diag. 78. Hematite (Fe_2O_3), on the other hand, is colored distinctly red and the reflectance increases from about 21/2 % in the blue to about 13 % in the red region (Curve 78.1). For a comparison, see also the similar curve for limonite ($Fe(OH)_3$) in Diag. 103 (Curve 3).

Tolchel'nikov then collected samples from soils developed all on the same type of sediment, a loess-like deposit, so that the granulometric and the mineral composition remained approximately constant. Besides the natural soil samples, two samples were prepared artificially, one from which all organic matter and iron oxides were removed (no. 150) and one from the combination of equal amounts

of humic acid, fulvic acid, Fe_2O_3 and Fe_3O_4 (no. 100). All samples were dried and their total visible light reflectance was determined. The results are presented in Fig. 37 and Table 25. The regular distribution of points in the plot

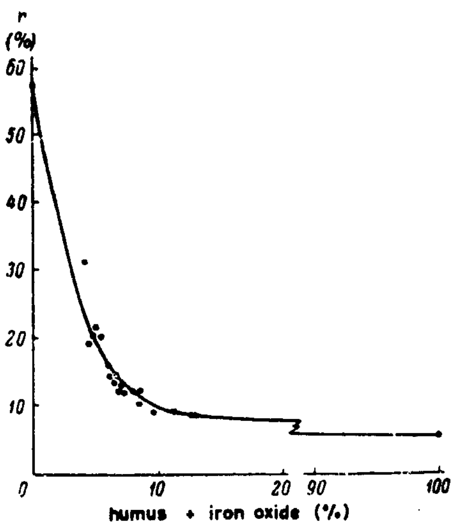


Fig. 37 Dependence of visible light reflectance on humus and iron oxide content for heavy loamy soils (from TOLCJS60PFT).

demonstrates that the general brightness is governed by the sum of humus and iron oxides. This can be explained by the fact that both components reflect light similarly and, also, that there occur only small variations in the humus iron oxide ratio in the soils of the study area. A brightness maximum was observed for the sample devoid of humus and iron oxide (58 %). The reflectance then decreases with increasing content of these two substances. The most rapid change occurs between O and 10 % humus-iron oxide content. Afterwards, the drop in brightness gets gradually smaller. Between 10 and 100 % humus-iron oxide the reflectance changes from 10 to 6 % only. This behaviour is the result of the physical properties of humus and iron oxides. Both are distributed in the soil in colloidal form and envelope the mineral grains and microaggregates as a thin layer. When their content is low, a large part of the grain surfaces is uncovered, and a small change of the amount of humus and iron oxide brings about a considerable change of brightness. Once the particles are covered by a continuous layer, an increase of the humus-iron oxide-percentage has practically no visible effect any more.

It should be noted that the curve in Fig. 37 is based on samples of clayey soil only. Coarse-grained material with an equal amount of humus and iron oxide

would be darker and the drop of the reflectance curve with increasing humus-iron oxide-content would be steeper.

The spectral reflectance characteristics of soils are governed basically by the ratio humus/iron oxide. For a low ratio, spectral curves have, in general, a distinct maximum in the red spectral zone, because then the color of Fe_2O_3 dominates. An increase of the humus content relative to the iron oxide, i.e., an increasing ratio, levels out the spectral curve more and more. In addition, the type of the organic material present in the soil has also an influence on the spectral distribution of reflected light. As would be expected from the curves shown in Diag. 77, soils with a dominance of fulvic acid reflect more intensively in the red band than in the rest of the visible spectrum. Examples for the spectral reflectance of different types of soils having various humus/iron oxide ratios and contents of fulvic and humic acid will be given in section 4.1.8.

Sources: LJALKS80IOP, TOLCJS60PFT, TOLCJS66DAP.

4.1.4 Reflectance as a function of mineralogical composition of soils

In section 4.1.1 we discussed for a number of different minerals the dependence of general brightness upon grain size as reported by J.S.Tolchel'nikov. In Diags. 79 and 80 the spectral reflectances of these minerals are directly compared for the fraction with particles smaller than 0.1 mm. Average percentage reflectance for the blue, the green and the red spectral interval as well as for the whole visible spectrum are given in Table 26. Quartz, biotite and

Table 26 Reflectance of various minerals for the granulometric class < 0.01 mm in selected spectral intervals (based on data reported in TOLCJS60PFT)

SRC = Spectral reflectance curve

Mineral		Reflectance in %				SRC no.
	Spectral region	Blue	Green	Red	Visible	
	Wavelength (mμ)	430-490	510-590	610-670	430-670	
Quartz		92.9	93.0	93.5	93.1	79.1
Biotite		7.4	7.4	7.4	7.4	79.2
Muscovite		59.3	60.3	60.2	60.0	79.3
Microcline		61.4	71.7	80.7	71.3	80.1
Garnet		11.0	18.3	30.3	19.7	80.2
Epidote		18.6	34.7	36.5	30.3	80.3

muscovite are completely spectrally neutral or nearly so, whereas microcline, garnet and epidote have curves which slope upward from the blue to the red part of the spectrum. Also orthoclase, the spectral reflectance curve of which is not shown here, has a maximum in the yellow and red region. The differences with respect to general brightness are great, quartz being the brightest (93 % reflectance) and biotite the darkest (7 %) among the minerals investigated.

It must be expected that, as a result of these variations, soils developed on parent materials differing from each other with respect to mineralogical composition will be reproduced in contrasting tones on air photographs. As a matter of fact, soils having different spectral intensities show up in different colors on color air photos, i.e., they may have red, yellow or gray color tones. As an example, see in Diag. 97 the spectral curves of three soils being approximately equal with respect to texture (loamy sand), but differing in color. The color change is probably mainly due to variations in mineralogical composition. Its influence on spectral reflectance and, hence, on color should not be overestimated, however. Differences in spectral reflection characteristics are not only caused by variations in the content of minerals, but also by other factors, among these especially humus and iron oxide concentration. In northern Kazakhstan, for example, a consistent correspondence between color tone and mineralogical composition is confined to the hills, where various geological strata crop out. For the majority of the level terrain loess-like sediments form the parent material and here, small differences in content of minerals do not produce significant tonal changes on air photos (compare with section 5.1). On the other hand, M.A. Romanova, in her study on the possibilities of surveying sand deposits in west Turkmenia and the northwest Caspian region from the air, came to the conclusion that she was able to determine the mineralogical composition of deposits from spectral reflectance curves by applying regression and correlation techniques. Since her work is available as an English translation (ROMAMA64ASS) we shall not go into details here.

Sources: ALEKVA60SDP, ROMAMA62OTS, (English translation: ROMAMA64ASS) TOLCJS60PFT.

4.1.5 Reflectance as a function of soluble salt content

Soils in arid areas may have a high salt content which affects reflectance. This influence is especially pronounced if a salt crust is formed on

the soil surface. Diag. 76 shows the spectral reflectance curves for three types of soluble salts common in soils, namely sodium carbonate (Na_2CO_3), sodium chloride (NaCl) and potassium hydrogen sulfate ($KHSO_4$). All these salts, being white materials, have an almost uniform and very high reflectance (65 - 89 %) throughout the whole visible spectrum. As a result of this color neutrality, soils containing free salts do not change their spectral characteristics, unless the salts form a compact superficial crust (see Curve 102.2), but they become, of course, considerably brighter.

To investigate this change of brightness. J.S.Tolchel'n'kov prepared a number of artificial soil samples by taking material from a base saturated meadow soil and adding various amounts of calcium carbonate. To simulate natural conditions as closely as possible the samples were moistened and dried repeatedly. The results of the reflectance measurements made on these samples are reported in Table 27. It can be seen that reflectance in % is approximately

Table 27 Dependence of soil reflectance on calcium carbonate content (from TOLCJS60PFT)

$CaCO_3$ content in %	Reflectance in %
0.0	2.7
0.5	3.0
2.5	4.3
5.0	5.5
12.5	7.5
25.0	12.0
50.0	25.0

directly proportional to $CaCO_3$ content in %. It should be noted that this rule holds only for free salt. Adsorbed cations do not have an influence on soil reflectance directly. They may, however, affect reflectance indirectly by changing the surface structure of soils. This will be discussed in section 4.1.6.

The influence of a surface salt crust on reflectance is illustrated by Diags. 101 and 102, which are based on dat collected by K.S.Ljalikov and I.N. Belonogova in southwest Turkmenia. Curve 101.1 represents the spectral reflectance of a dark-gray clay soil which is covered by a thin salt crust. Curve 101.2 shows the spectral characteristics of the same soil, but after removal of the crust. The crust intensifies reflectance 2 to 3 times. Curve 102.2 represents a fresh and moist salt crust which covers the soil completely, so that the reflectance is high and neutral (80 %). The reflectance of the same type of surface

when soiled by sand and dust is given by Curve 102.3. Compared with the previous curve, it is lowered by a factor of 1.3 to 2.5. Also, as a result of the characteristics of the soiling material, the shape of the curve changes and now slopes upward toward the red end of the visible spectrum.

Sources: LJALKS60IOP, TOLCJS60PFT, TOLCJS66DAP.

4.1.6 Reflectance as a function of surface structure

Differences in physical and chemical properties of soils manifest themselves in differences of surface structure (Russ.: "faktura"). For example, the surface of common chernozems is, in general, flat and has only a few narrow cracks here and there (see a in Fig. 38). Heavily solonized chernozems, on the other hand, have a clumpy structure with large cracks (see b in Fig. 38). On solonetz soils one finds a dense network of narrow and broad fissures, whereby the polygons in between have a smooth surface (see c in Fig. 38). The surface of solonchaks is almost structureless and covered by salt efflorescences (see d in Fig. 38). Differences in surface structure are much more pronounced on undisturbed soils, but they can, to some extent, also be observed on plowed fields.

Due to the presence of microshadows, rough surfaces appear as a mosaic of bright and dark areas. One factor governing the overall reflectance of such surfaces is the intensity of light remission from individual shadow and light areas. In Table 23 the percent reflectance of microelements of some soil types is shown. It can be seen that shadow areas, i.e., areas not receiving direct sunlight, have a brightness which is about 10 times lower than that of areas illuminated by the sun. Deep and wide cracks on the soil surface are even darker.

The ratio between illuminated and shady areas depends on day-time (i.e., the sun's altitude), cloudiness and other factors. The more cracks on a surface and the lower the sun, the darker the appearance of this surface, because shadow areas increase at the expense of light areas. J.S. Tolchel'nikov made investigations on the influence of surface structure on photo tone under field conditions in northern Kazakhstan. He took large-scale terrestrial photographs (1 : 7) and measured on them the area covered by shadows in percent. Some of his results are provided by Table 29. Tolchel'nikov noted that during "air photographic hours" the extent of the areas lying in the shadow did not change more than 5 - 6 % and concluded that, within certain limits, the change of solar altitude does not affect overall reflectance significantly.

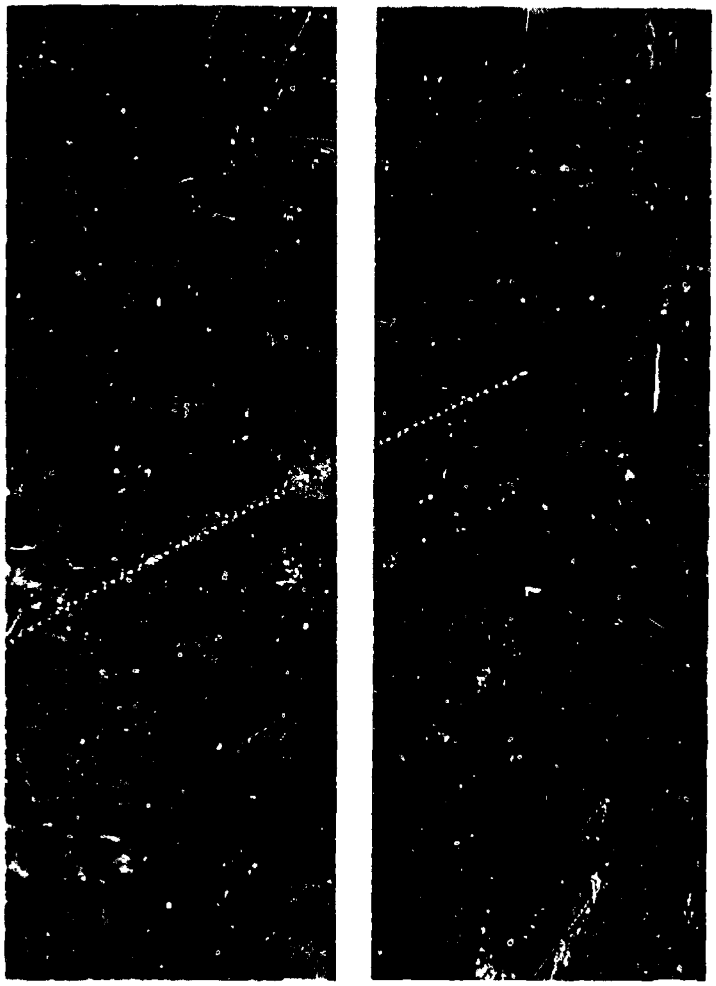


Fig. 38
Terrestrial photos showing the surface structure of various types of soil. Scale approx. 1 : 6 (from TOLCJS60PFT).
a = common chernozem, b = heavily solonized chernozem, c = crust solonetz, d = solonchak with salt efflorescences.

Table 28 Visible light reflectance of the microelements of various soil types as observed on Sept. 15, 1.00 PM in northern Kazakhstan (from TOLCJS60PFT)

Soil type	Reflectance in %		
	Surfaces illuminated by sun	Surfaces in shadow	Cracks (20 cm deep and 5 cm wide)
Podzol	9.3	1.0	
Heavily podzolized soil	15.4	1.2	
Humic gley soil	4.6	0.4	0.1

Table 29 Extent of shadow areas created by surface structure of some soils (from TOLCJS60PPT)

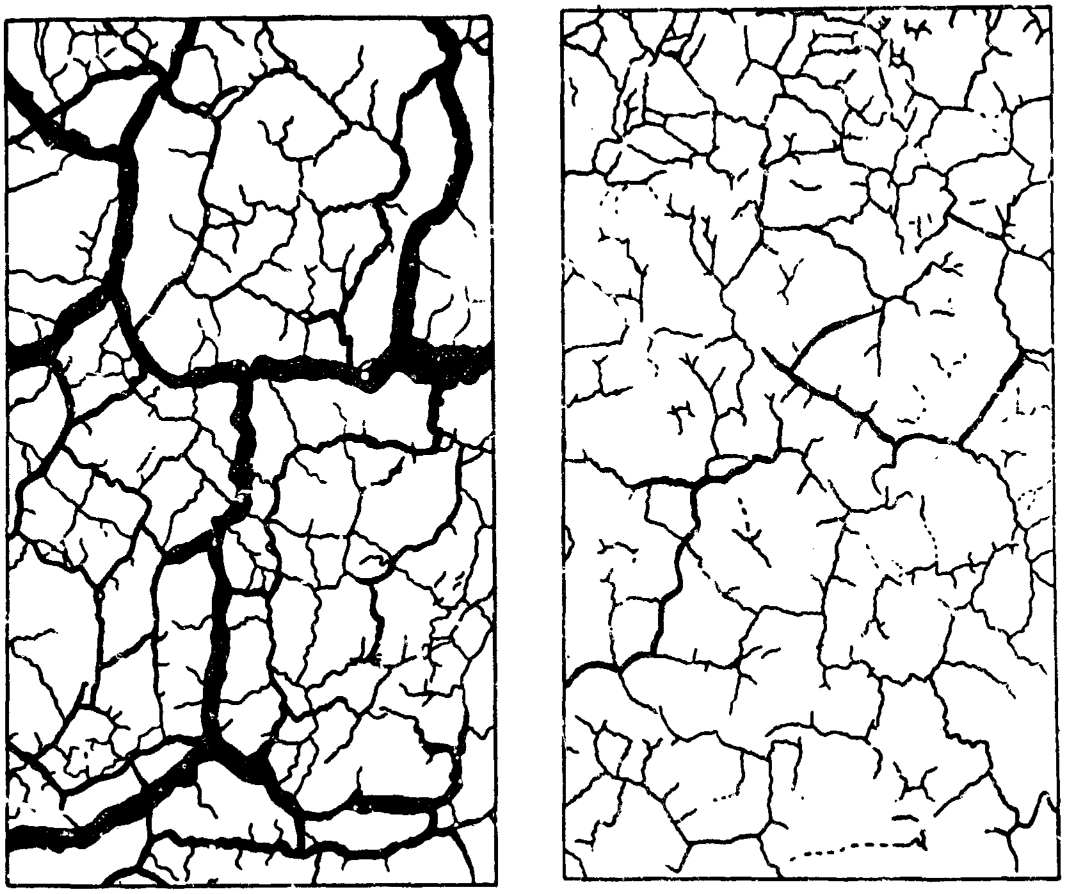
Soil type	% of total area covered by shadows created by surface structure at 10 AM in June and July
Chernosems	under 1
id., heavily solonized	2
Solonetzs	5 - 7

I.N. Belonogova and B.V. Vinogradov studied the influence of polygonal cracks on takyr soils in west Turkmenia on reflectance and photo tone. The larger but less common elements of the microstructure, such as holes, knobs and macropolygonal cracks can be recognized individually on air photos with a sufficiently large scale. The more frequent elements of the ultramicrorelief, as the authors call it, especially small cracks, cannot be recognized, but they have an integral effect upon photo tone. As a rule, surfaces with no or only a few cracks are lighter than those with numerous cracks. Heavily sodic[19)] soils tend to produce more and larger cracks than soils with a lower content of Na cations in the adsorption complex. As an example, the total length of large, medium and small cracks within an area of 1 cm^2 is given for two different takyrs in Table 30 (compare also with Fig. 39).

Table 30 Intensity of crack formation in takyr soils (from BELOIN58NPI)

Type of soil	Class of cracks	Total length within 1 dm^2
Highly sodic takyr	large (width 0.5-1 cm)	18 cm
	medium (2-3 mm)	31 cm
	small (ca. 1 mm)	65 cm
Weakly sodic takyr	large	0 cm
	medium	10 cm
	small	89 cm

S.V. Belov, in an experiment carried out in the Tomsk region, also investigated the influence of surface structure on reflectance. Artificial furrows were made in dry sand and measurements made with the furrows perpendicular and parallel to the shadow direction. The results were compared with the reflectance of undisturbed sand (see spectral curves in Diag. 99 and Fig. 40). As



a b

Fig. 39 Surface structure of takyr soils. Scale approx. 1 : 2.5 (from BELOIN58NFI).
a = Highly sodic soil, b = weakly sodic soil.

far as the general brightness is concerned the smooth surface reflects light most intensively, followed by the surface with furrows parallel and that with furrows perpendicular to the direction of cast shadows. The differences in all three curves are only small, however. It seems that, in the last case, the lower brightness of the shadow areas is almost fully compensated for by the higher brightness of the sloping surfaces exposed to full sunlight. Also, a comparison of the three curves indicates that color is not affected by surface structure.

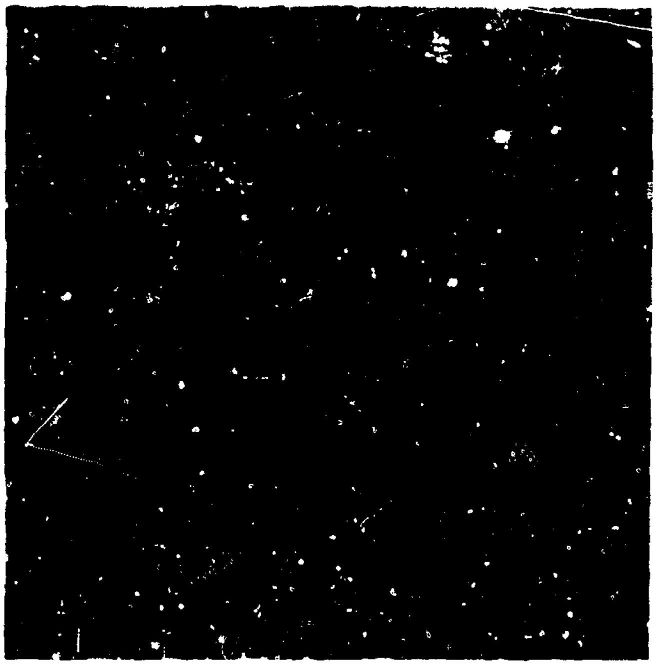


Fig. 40
Terrestrial photo of artificial ridges made on the surface of a sandy soil with different orientations. Scale approx. 1 : 7 (from TOLCJS60PFT). a = perpendicular to cast shadow direction, b = at 45° to cast shadow direction, c = parallel to cast shadow direction, d = level surface without ridges.

Sources: BELOIN58NFI, BELOSV59AFL, ROMAMA62OTS (English translation: ROMAMA64ASS), TOLCJS60PFT.

4.1.7 Angular dependence of reflection

As early as in the late 1920's, V.S.Kulebakin made investigations on how light was scattered by various terrain surfaces. This study was undertaken in connection with problems of artificial outdoor illumination, however, and measurements were carried out under high oblique angles only (30° angular altitude and less). Consequently, his findings have a very limited application only to the case of air photography, and we shall not discuss them here.

Recently, J.S.Tolchel'nikov carried out measurements with a luxmeter (for the method of measurement see section 1.3.1) in the Karakum depression to investigate the dependence of the brightness of soils upon the angle of observation. Readings were taken at oblique angles at 15° intervals in two planes, one perpendicular and one parallel to the cast shadow direction. All observations were made on May 5, between 32 and 38° of solar altitude. The results in the perpendicular plane are shown in Fig. 41 in the form of a light scattering indicatrix. Curve 1 stands for a solonchak, 2 for a takyr and 3 for sand.

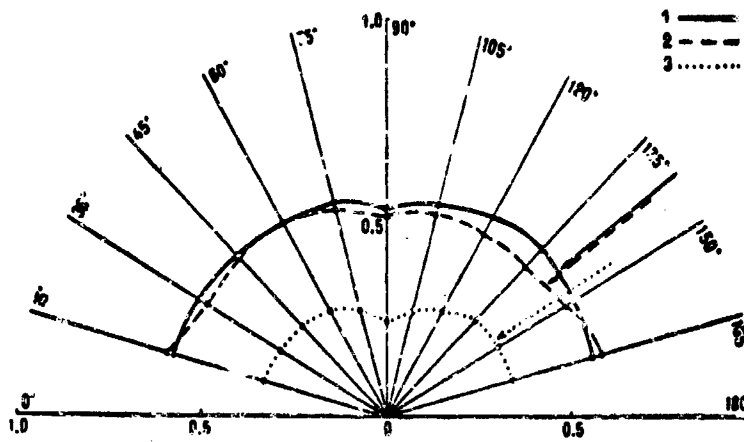


Fig. 41 Indicatrix for the scattering of light from three different soil types in a plane perpendicular to the cast shadow direction (from TOLCJE65IRE). 1 = solonchak, 2 = takyr, 3 = sand.

The solonchak looks darkest when seen from vertically above. With an increasing oblique angle of observation there is first a more intensive reflection of light. Later on it remains about constant. The author gives the following explanation for this findings: The spongy surface of the solonchak creates microshadows which are seen to the full extent in the vertical view, but which become more and more hid[illegible] t an increasing deviation of the direction of observation from the vertical. Eventually, they are covered completely by elements of the microstructure and there is no further change of brightness with a change of angle.

The takyr has more orthotropical properties, i.e., reflectance changes to a lesser degree with an alteration of the angle of view. Only for extreme high oblique angles can a slight increase be observed. This behavior is due to the smoothness of the crusty takyr surface from which shadow creating microelements are almost completely absent.[20]

Sand has a regularly uneven mat surface. Its light scattering indicatrix stands, according to the author, between that of the solonchak and that of the takyr with respect to the degree of change with an alteration of the viewing direction. Fig. 41, however, suggests that the changes, expressed in percent of the reflection vertically upwards, are greater for sand than for the solonchak.

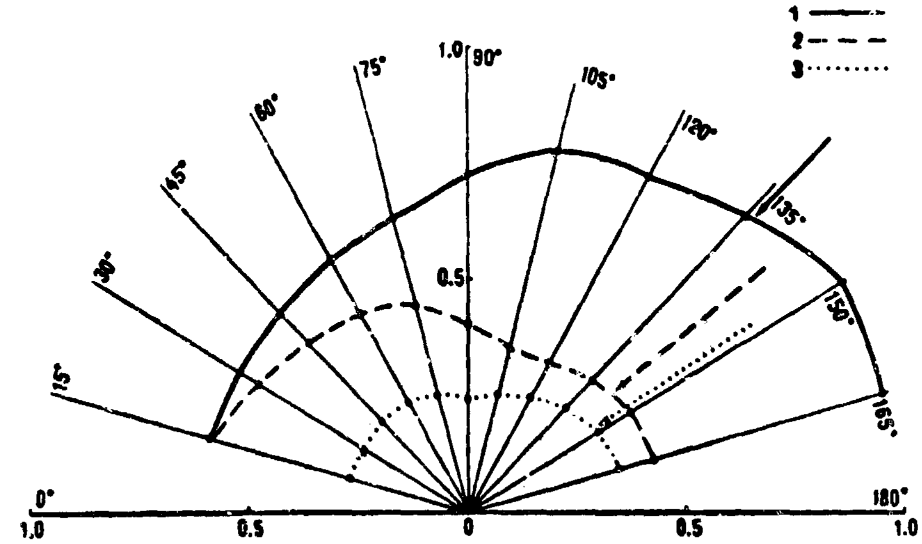


Fig. 42 Indicatrix for the scattering of light from three different soil types in a plane parallel to the cast shadow direction (from TOLCJS65IRE). 1 = solonchak, 2 = takyr, 3 = sand. The arrows indicate the direction of the incident sunlight.

Fig. 42 provides the results of the measurements made in the parallel plane. Here the dependence of reflection on the angle is much more pronounced. The solonchak looks much brighter when seen in the direction of the sun's illumination than from the reverse side. The reason is that the illuminated sides of the microelements are dominant in the first case, the shady sides in the second case. The takyr surface behaves conversely: Due to the smoothness of its surface there is a certain amount of mirror-like reflection. Finally, the sand surface reflects light in an almost diffuse manner, i.e., reflected light is scattered about equally in all directions. This is in good agreement with findings of M.A.Romanova. She reports that sand constitutes a nearly orthotropically reflecting surface and that its indicatrix remains spherical as long as the angle of return does not deviate more than 50° from the vertical (see also indicatrices of diffusion for barkhan sand published in ROMAMA64ASS).

Sources: KULEVS29BAB, KULEVS30LRE, ROMAMA62OTS (English translation: ROMAMA64ASS), TOLCJS65IRE.

4.1.8 Comparison of soil types

The most comprehensive comparative study to date on the spectral reflectance of soils of various geographical zones has been carried out by J.S. Tolchel'nikov. This research was combined with an analytical investigation of individual factors affecting reflectance, the results of which we have reported in the previous sections. The following is a summary of the most important findings:

1. Soil components which lower the general reflection of visible light are humus and iron oxides.

2. Components which give rise to an increase in general reflectance include quartz, carbonates, bicarbonates, chlorides, kaolinite and alumina.

3. The wavelength dependence of light reflection is governed in the first place by the humus/iron oxide ratio. Soils with a low ratio tend to have a distinct reflection maximum in the red spectral zone, soils with a high ratio approximate a type of reflection which is spectrally neutral.

4. A second factor influencing the spectral intensity distribution is the composition of the organic matter present in the soil, i.e., the ratio between humic and fulvic acid as explained in section 4.1.3.

The results of Tolchel'nikov's comparative investigation are presented in Diags. 109, 110 and 112 - 115 as well as in Table 52. All samples were collected from the uppermost horizon of soils and they were airdry when measured. Their content of humus and Fe_2O_3, the humus/iron oxide ratio, and, as far as available, their granulometric composition is given in Table 31. The following observations can be made for the individual soil types:

1. Soddy podzolic soil (sample I[21], Curve 113.2): It has a low humus content and, consequently, a relatively high reflectance. The humus/iron oxide ratio is high so that the spectral curve has only a weak upward trend toward the longer wavelengths.

2. Podzolic gley soil (sample II, Curve 113.3): Its humus content is still lower than that of the soddy podzolic soil. Due to the anaerobic conditions it is relatively rich in FeO and the spectral reflectance curve has two weak maxima, one in the green part and one in the red part of the spectrum.

3. Cryptopodzolic peat soil (sample III, Curve 113.1): The peat soil has an extremely high content of organic matter and, therefore, a low general reflectance. The dominance of fulvic acid causes the spectral curve to swing upward from the blue to the red band.

4. Gray forest soil (sample IV, Curve 114.1): This soil, developed under a cover of deciduous forest, has more humus than both the soddy podzolic and the podzolic gley soil and, consequently, a lower reflectance. The humus/iron

Table 31 Analytic data for soil samples used to compare the spectral reflectance of various soil types (from TOLCJS590TP and TOLCJS60PPT)

Sample no.	Soil type	Granulometric composition (%)		Humus (%)	Fe_2O_3 (%)	$\frac{\text{Humus}}{Fe_2O_3}$	Hygroscopic moisture capacity (%)
		Fraction >0.01 mm	Fraction <0.01 mm				
I	Soddy podzolic soil	-	-	2.5	1.6	1.6	-
II	Gley podzol	-	-	1.2	-	-	-
XII	Cryptopodzolic peat soil	-	-	71.0	2.6	27.2	-
IV	Gray forest soil	-	-	4.7	4.0	1.2	-
V	Meadow soil	-	-	10.4	5.5	1.9	-
136a	Common chernozem	35.7	64.3	4.1	5.3	0.8	5.5
VI	id.	-	-	8.2	4.5	1.8	-
67	Meadow chernozemic soil	38.8	61.2	12.2	4.3	2.9	6.0
144	Carbonate chernozem	34.1	65.9	2.6	4.2	0.7	4.1
VII	Chestnut soil	-	-	3.5	3.9	0.9	-
142	Heavily solonized chernozem	31.3	68.7	4.2	4.2	1.0	4.2
VIII	External solonchak	-	-	4.3	2.9	1.5	-
141	Shallow solonetz	49.3	50.7	1.4	3.8	0.4	4.0
IX	id.	-	-	1.4	3.8	0.4	-
145	Gley soloth	53.5	46.5	0.7	1.2	0.6	14.5
X	id.	-	-	1.1	2.9	0.4	-
XI	Sierozem	-	-	0.5	1.8	0.3	-
XII	Eroded latosol	-	-	0.8	4.2	0.2	-

oxide ratio is high and there is only a weak increase of spectral reflection intensity toward longer wavelengths.

5. Meadow soil (sample V, Curve 114.3): This type is rich in humus and its humus/iron oxide ratio is high. As a result, its reflectance is low and close to spectral neutrality.

6. Common chernozem (sample VI, Curve 114.2 and sample 136a[21]), Curve 109.1): This soil has a rather high humus content and the humus/iron oxide ratio is around 1 or higher. Therefore, it has a low brightness and a weak upward trend toward the red end of the spectrum in general. There is, however, some difference between the two samples. The spectral curve of 136a with a lower humus/iron oxide ratio (0.8) has an upward trend which is more pronounced (r_{red}/r_{blue} = 1.56) than that of VI (r_{red}/r_{blue} = 1.34) with a higher humus/iron oxide ratio (1.8). This illustrates nicely the basic influence of this ratio on the shape of the spectral reflectance curve.

7. Meadow chernozemic soil (sample 67, Curve 109.2): Here again the humus content and the humus/iron oxide ratio are both high. Furthermore, humic acid dominates in the organic component so that the reflectance is low and very nearly neutral.

8. Carbonate chernozem (sample 144, Curve 109.3): Its humus content is considerably lower than that of the previous types. This leads, together with the concentration of carbonates, to a relatively high reflectance. The humus/iron oxide ratio is lower and the upward swing of the spectral curve throughout the visible wavelengths steeper.

9. Chestnut soil (sample VII, Curve 115.1): This soil has much less organic matter than the chernozem and, therefore, a higher brightness. Also, the ratio between humus and iron oxide is relatively low, so that the reflectance curve has a distinct maximum in the yellow and red part of the spectrum.

10. Heavily solonized chernozem (sample 142, Curve 110.2): Humus and iron oxide contents are similar to those in the common chernozem. Therefore, the general brightness is low. However, the spectral reflectance curve has a distinct maximum in the red band, which can be explained by the presence of fulvic acid in the organic component.

11. External solonchak (sample VIII, Curve 112.3): This soil has a relatively high humus concentration at the surface, but its influence on reflectance is masked by the presence of salts. The humus/iron oxide ratio is high. As a result, the spectral curve is high throughout and shows only very little variation.

12. Shallow solonetz (sample 141, Curve 110.1 and sample IX, Curve 112.1): Solonetz soils have a low humus content, causing a high general re-

flectance. The iron oxide concentration is relatively high and the spectral curves have a pronounced maximum in the yellow-red region.

13. Gley soloth (sample 145, Curve 110.3 and sample X, Curve 112.2): This type is still poorer in humus than the solonetz, at least in the upper part of the profile, since the organic matter is very mobile and washed out. Compared with other soils, the iron oxide content is also low, but the humus/iron oxide ratio is low, too. Consequently, the spectral reflectance curve is high and has a weak but constant upward trend with increasing wavelength.

14. Sierozem (sample XI, Curve 115.2): Again both the humus concentration and the ratio between humus and iron oxide are low. The general reflectance is high and the curve slopes upward toward the red end of the visible spectrum.

15. Eroded latosol (sample XII, Curve 115.3): This soil is poor in humus, but rich in iron oxide, which gives rise to an extremely low ratio between the two. In addition, the oxide is less hydrated than that in soils of temperate or cold regions. This causes the spectral curve to have a contrast between the red and the blue band which is greater than that of all other soils discussed here.

A summary of the results with average reflectances within the blue, the green and the red spectral interval and the ratio r_{red} / r_{blue} is given in Table 32. The author concludes that genetically different soil types are characterized by differences in spectral reflectance and that the red spectral region offers the best prospects for a separation of soil types. This latter conclusion is questionable, however, because it is based on spectral reflectance graphs with a linear percentage scale. A careful analysis of contrasts between individual soil types shows that the blue spectral region is rather better than the red on the average. This should not be overly generalized, however, and each particular case should be considered separately. Summarizing, it can be said that the blue spectral band seems to be better for a distinction of soils of the taiga, the forest steppe, the semi-desert and the desert zones with the exception of the sierozem which contrasts better with other soils in the red spectral region. This region also offers good prospects for separating chernozems from neighboring soil types.

V. L. Andronikov made some systematic investigation on the spectral reflectance of different soils of the forest steppe belt. His measurements are reproduced in Diags. 116 and 117 and summarized in Table 33. The humus content and the granulometric composition of these soils is provided by Table 34. The curves are ordered according to descending degree of podzolization and ascending degree of humus content. It can be seen that there is a regularity in the change of reflectance from the one type to the next. The brightness is highest for the heavily podzolized chernozem (Curve 117.3). Except for the extreme

Table 32 Reflectance of different soil types for selected spectral intervals (based on data reported in TOLCJS59OTP and TOLCJS60PFT)

SRC = Spectral reflectance curve

Sample no.	Soil type	Reflectance in %				Red/Blue	SRC no.
	Spectral region	Blue	Green	Red	Visible		
	Wavelength (mμ)	430-490	510-590	610-670	430-670		
I	Soddy podzolic soil	13.4	16.6	18.6	16.2	1.39	113.2
II	Gley podzol	20.8	21.9	21.3	21.3	1.02	113.3
III	Cryptopodzolic peat soil	4.9	8.5	11.2	8.2	2.28	113.1
IV	Gray forest soil	8.1	10.4	13.4	10.6	1.65	114.1
V	Meadow soil	4.0	4.6	5.8	4.8	1.45	114.3
136a	Common chernozem	7.3	9.5	11.4	9.4	1.56	109.1
VI	id.	6.4	7.3	8.6	7.4	1.34	114.2
67	Meadow chernozemic soil	4.3	4.8	5.4	4.8	1.26	109.2
144	Carbonate chernozem	17.3	24.1	28.4	23.3	1.64	109.3
VII	Chestnut soil	8.3	11.8	15.1	11.7	1.82	115.1
142	Heavily solonized chernozem	7.4	11.3	13.7	10.3	1.85	110.2
VIII	External solonchak	24.2	25.0	25.0	24.7	1.03	112.3
141	Shallow solonetz	19.8	28.1	31.5	26.6	1.59	110.1
IX	id.	12.8	17.6	21.2	17.2	1.66	112.1
145	Gley soloth	21.1	27.4	30.1	26.3	1.43	110.3
X	id.	18.8	20.5	23.2	20.8	1.23	112.2
XI	Sierozem	21.3	30.7	35.6	29.3	1.67	115.2
XII	Eroded latosol	11.4	27.0	38.1	25.6	3.34	115.3

Table 33 Reflectance of some soil types of the forest steppe zone for selected spectral intervals (based on data reported in ANDRVL58SPL)

SRC = Spectral reflectance curve

Soil type		Reflectance in %				Red/Blue	SRC no.
	Spectral region	Blue	Green	Red	Visible		
	Wavelength (mμ)	430-490	510-590	610-690	430-690		
Heavily podzolized light-gray forest soil		22.3	26.5	38.3	29.5	1.72	116.1
id., gleyish		18.3	24.6	33.9	26.1	1.85	116.2
Light-gray forest soil		9.3	13.1	21.6	15.1	2.32	116.3
Gray forest soil		8.4	12.0	19.0	13.5	2.26	117.1
Dark-gray forest soil		7.3	10.7	16.8	11.9	2.30	117.2
Podzolized chernozem		6.7	9.8	15.4	10.9	2.30	117.3

Table 34 Humus content and granulometric composition of forest steppe soil types (from ANDRVL58SPL)

Soil type	Humus content (%)	Granulometric composition (%) Fractions in mm					
		1.0-0.25	0.25-0.05	0.05-0.01	0.01-0.005	0.005-0.001	<0.001
Heavily podzolized light-gray forest soil	2.0	19.9	16.8	35.4	8.5	8.2	9.4
Gleyish light-gray forest soil	2.5	3.9	5.2	42.7	12.8	18.4	13.0
Light-gray forest soil	3.0	29.3	12.4	22.3	5.5	7.2	18.9
Gray forest soil	3.7	8.7	13.0	35.3	7.7	7.8	22.0
Dark-gray forest soil	5.4	7.7	5.2	31.4	9.4	10.4	28.8
Podzolized chernozem	6.8	8.4	5.9	30.4	8.8	10.7	27.5

lower end of the visible spectrum all curves have a constant upward trend toward the red end and are similar in shape. Andronikov reaches the same conclusion as Tolchel'nikov, namely that the use of the red spectral zone would be recommendable for air photography. However, this conclusion again is based on the

interpretation of differences on a linear percentage scale. The logarithmic plots suggest that, if at all, the blue band is slightly better in contrasts.

The reflectance of the same soil types (except for the gleyish gray forest soil) is also shown in Diags. 118 and 119, but these data were obtained for samples with a "natural moisture content", i.e., hygroscopic moisture. The respective values are given in Table 35. A comparison with the foregoing results

Table 35 Visible light reflectance of forest steppe soil types with natural moisture content (based on data reported in ANDRVI58SPL)

Soil type	Natural moisture in %	Visible light reflectance in %	SRC no.
Heavily podzolized light-gray forest soil	2.95	21.9	118.1
Light-gray forest soil	6.96	13.3	118.2
Gray forest soil	7.63	12.1	119.1
Dark-gray forest soil	9.52	10.1	119.2
Podzolized chernozem	10.00	7.6	119.3

(see Table 33) demonstrates that contrasts are slightly enhanced under these circumstances. If soils are equally moist their contrast is lower, however. For example, the contrast between the heavily podzolized light-gray forest soil and the podzolized chernozem is 2.9 : 1 (21.9 % : 7.6 %) for the state of natural moisture (2.95 % for the former and 10.0 % for the latter soil, respectively), but only 1.9 : 1 (14.6 % : 7.8 %) for 10 % moisture in both soils. Compare this with the contrast for air-dry samples, which is 2.7 : 1 (29.5 % : 10.9 %). The conclusion is that air photos for soil interpretation should not be taken immediately after rains, when there is everywhere a more or less equal moisture content, but at rather low or medium moisture contents. Experience has shown indeed that best contrasts are obtained during the drying out of soils, when there exist moisture differences caused by variations of soil texture and microrelief.

E.S. Arcybashev has reported some results of airborne measurements taken from an altitude of 200 m. In Diag. 107 the spectral reflectance curves of a solonchak, a takyr and a stable sand surface are presented. All curves swing upward with an increase in wavelength within the visible spectrum. In the infrared the reflectance has a tendency to remain constant or become somewhat lower and contrasts are lower, too. Consequently, the near infrared spectral region is not

suitable for air photography of desert soils. A further reason for not making use of infrared radiation is the fact that vegetation has a much higher reflectance in the infrared, approximating that of desert soils, so that distinguishing vegetated and unvegetated surfaces would be difficult (compare with section 3.5). It should also be noted that Arcybashev's airborne data are higher than those obtained by Tolchel'nikov for corresponding soils under laboratory conditions. There may be several reasons for this fact, among them intervening haze light in the case of the aerial measurements and systematic instrumental differences.

Some remarks on the reflectance of semi-desert and desert soils are given in section 3.5 in conjunction with a discussion of vegetation types associated with them.

Sources: ANDEVL58SPL, ARCYES62ISJ, TOLCJS59OTP, TOLCJS60PFT, TOLCJS66DAP.

4.2 Spectral reflectance of road surfaces

Spectral reflectance curves obtained by V.A. Alekseev and S.V. Belov for some dry and wet road surfaces are given in Diags. 95 and 96. A dirt road on yellowish-gray sand, a road with stone pavement and one with asphalt pavement were measured. All curves show a gradual increase of reflection intensity from the blue to the near infrared, with the exception of the wet stone pavement which has a weak minimum at 770 mμ. The reflectance of all three surfaces is 2 to 3 times lower when wet.

The reflectance of both the stone and the asphalt pavement is very similar and there is hardly any contrast between the two except in the blue-green spectral region when the surfaces are wet. The dirt road has the most intensive reflectance almost throughout. However, it contrasts significantly with the other two types only in the infrared.

Source: ALEKVA60SDP.

5. Results of measurements: Rocks[22)]

The spectral reflectance and, hence, the color of sedimentary rocks depends in the first place on their content of iron, manganese and carbon compounds. The degree of oxidation governs the color of iron compounds. Those with bivalent iron usually are green or blueish-green whereas those with trivalent iron have yellow, brown or red tints.

K. S. Ljalikov and I. N. Belonogova, in a study on the spectral reflectance of some types in the area of the Great and the Small Balkhan (southwest Turkmenia), made the following experience: Although the rocks occurring in the area are of different origin (limestones, shales and sandstones) and vary with respect to mineralogical composition, all investigated types could, on the basis of their color, be assigned to one of two groups, namely either to red-brown rocks or to green rocks. Curves 1 and 2 in Diag. 103 show for both types the spectral reflectance of a freshly broken sample. It can be seen that the reddish rock has a reflectance maximum in the red and the green rock one in the green spectral region, as would be expected on the basis of their color. The color of red rocks probably is caused by a high concentration of limonite (compare with Curves 78.1 and 103.3). It is more difficult to explain the color of the second group of rocks. It may be caused by glauconite, but this conjecture needs verification. For a comparison of the spectral reflectance of differently colored clays, the reader is referred to Diag. 98.

Some further examples for the spectral reflectance of various rock types, including pyroxene porphyrite, amphibole gabbro, biotite granite, calcareous sandstone, etc. can be found in ROMAMA64ASS.

Sources: LJALKS60IOP, ROMAMA62OTS (English translation: ROMAMA64ASS).

5.1 Influence of weathering on rock reflectance

In most cases, the spectral reflectance of subaerial rock surfaces is different from that of freshly broken rock. According to K.S. Ljalikov and I.N. Belonogova, who made observations in the desert zone, the reasons are the following:

1. A thin cover of foreign material deposited by wind or water may overlie the rocks.

2. Lichens may grow on the rock. An example for the change of reflectance produced by a lichen cover is provided in Diag. 106. Here, Curve 1 constitutes the reflectance of yellow-gray rock, Curve 2 that of the same type of rock but overgrown by brown-yellow lichens. Due to the color of this vegetational cover the color of the rock surface does not alter significantly, but its brightness drops by a factor of about 2.5.

3. As a result of the weathering process the rock surface is partly destroyed; fissures develop and easily soluble or non-resistent components are removed. An example is given in Diag. 105, where the reflectance of unweathered green rock is compared with that of weathered rock of the same type. The brightness of the latter is considerably higher.

4. A thin salt crust consisting of easily soluble salts, such as sodium chloride, natron sulfate, magnesium sulfate or gypsum may develop on the surface. These salts are washed away during rains and they are typical for dry solonchak areas only (see example in Diag. 101, discussed in section 4.1.5).

5. In very hot areas desert varnish may be formed. Diag. 104 shows a comparison of the reflectance of unweathered volcanic rock of yellow-green color with that of the same type of rock covered by black desert varnish. Accordingly, the general brightness drops and the spectral reflectance curve assumes a more neutral shape.

I. N. Belonogova and B. V. Vinogradov report that differences in the mineralogical composition of rocks, which originally give rise to differences in spectral reflectance characteristics, may be levelled out during the process of soil formation. They mention examples from western Turkmenia where they studied the reflectance of clay sediments originating from various rocks and deposited in depressions. They found that the loss of spectral reflectance differences was especially obvious for the formation of takyrs and takyr-like soils. Diag. 111 shows the spectral curves of two takyrs developed on colluvial material originating from two different types of shale. Nevertheless, the two curves are almost identical. A loss of contrast is apparent already for the weathered surfaces of different rock types if one compares them with freshly broken surfaces. After some time, all materials approximate a final weathering product, which is rich in colloidal particles and colored by iron compounds.

Sources: BELOIN58NFI, LJALKS60IOP.

2. Lichens may grow on the rock. An example for the change of reflectance produced by a lichen cover is provided in Diag. 106. Here, Curve 1 constitutes the reflectance of yellow-gray rock, Curve 2 that of the same type of rock but overgrown by brown-yellow lichens. Due to the color of this vegetational cover the color of the rock surface does not alter significantly, but its brightness drops by a factor of about 2.5.

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Sources: BELOIN58NFI, LJALKS60IOP.

Annotations

1 See the indicatrices of diffusion in ROMAMA62OTS (English translation: ROMAMA64ASS).

2 In more recent publications this instrument is being referred to as Universal Photometer FM-2. It has to be assumed that the FM-2 is an improved version of the FM. It is, however, not known to the authors of this report, what exactly the improvements are.

3 The transmission width of interference filters is usually defined as so-called "half width", i.e., the spectral interval of transmission is given between wavelengths at which the transmissivity is half the maximum. It may be assumed that the values given in Table 1 refer to half widths.

4 See for example G.W.Snedecor: Statistical Methods. 5th edition. The Iowa State University Press, Ames, Iowa 1962.

5 For a description of Russian aerial films see also D.Steiner: Technical aspects of air photo interpretation in the Soviet Union. Photogrammetric Engineering, vol. 29, no. 6, pp. 988 - 998, 1963.

6 S.V.Belov and A.M.Berezin: Znachenie uslovji aerofotografirovanija i razlichnykh tipov aeroplenok dlja izuchenija lesov (The importance of the air photographic conditions and the different types of aerofilms for forest surveying). Trudy Laboratorii Aerometodov, vol. VI, p. 146 - 175, Akademia Nauk SSSR, Moscow/Leningrad 1958.

7 The designation "Spectrozonal Computing Spectrovisor" is the reporters'. In the original Russian paper (KOLCVV66SAP) the technique is called "spektrometricheskaja aeros-emka s vychislitel'nym ustrojstvom", i.e., spectrometric air photography with a computing device.

8 L.S.Berg: Die geographischen Zonen der Sowjetunion. Vol. I and II, 437 + 604 pp. German translation of "Geograficheskie zoni Sovetskogo Sojuza", 3rd edition, Moscow 1947 and 1952. B.G.Teubner, Leipzig 1958/59.

9 M.S.Simakova: Soil mapping by color aerial photography. 81 pp., English translation of "Metodika kartirovanija pochv Prikaspijskoj nizmennosti po materialam aerofotos-emki" in "Pochvenno-geograficheskie issledovanija i ispol'zovanie aerofotos-emki v kartirovanii pochv" (Pedological-geographical investigations and the use of air photographs for soil mapping), Academy of Sciences of the USSR, Moscow 1959. Israel Program for Scientific Translations, Jerusalem 1964.

10 The density (Russian "polnota") is a measure which expresses the ratio between the basal area (sum of sectional planes at breast height per unit area) of the forest stand in question and that of an average stand as specified in productivity tables (usually called "normal stand").

11 This is the most recent paper by J.S.Tolchel'nikov. It repeats the findings described and discussed in TOLCJS60PFT. The collection of spectral reflectance curves contains references to this latter paper only.

12 The term "liman" designates a "lagoon" in the Black Sea area, but a usually dry depression, flooded only periodically or episodically, in areas further east.

13 V. Ljubimenko: Materija i rastenija (Matter and plants). Leningrad 1924.

14 V.N. Ljubimenko: Fotosintez i khemosintez v rastitel'nom mire (Photosynthesis and chemosynthesis of plants). Sel'khozgiz, Leningrad 1935.

15 N.A. Bajdalina: Anatomo-fiziologicheskie issledovanija elovogo podrosta (Anatomical-physiological investigations on the growth of spruces). Trudy Lesotekhnich. Akademii S.M.Kirova, vol. 73, 1956.

16 The reader will note that, although the measurements in the Leningrad area were taken with solar altitudes comparable to those in the case of the Tomsk area observations, they indicate a considerably lower contrast between the different angles of observation. This may, at least in part, be due to the fact that the Leningrad data were obtained with the spectrograph having a smaller tilt angle (25°) and a larger angular field (LS-2) with $2\beta = 18^{\circ}$) compared with the investigations in the Tomsk area, where the tilt angle was 30° and the angular field 12° (LS-3).

17 There is a discrepancy between this value and the curve for sample 104 in Fig. 35, which shows a light reflectance of about 31 % at 0 % moisture. The corresponding values indicated by the other curves in Fig. 35 are in agreement with those listed in Table 25.

18 Takyrs are compact soils developed on clayey material deposited in depressions of arid areas. They usually have a zone of salt accumulation at some depth and their adsorption complex is more or less saturated with sodium. They may be classified as internal solonchaks or solonetz soils (see L.S. Berg[8], vol. II, p. 130).

19 The Russian authors use the terms "sil'nosoloncevatyj" and "slabosoloncevatyj", which means "heavily solonized" and "weakly solonized", respectively. Since the contraction and, hence, the formation of cracks is a characteristic of non-saline sodic soils which occurs during the period of exsiccation, it

must be assumed that the more precise meaning is "heavily sodic" and "weakly sodic", respectively.

20 This last statement is contradictory to what was said about takyrs in section 4.1.6, where they were described as having a polygonal surface created by cracks. Cracks are present during the dry period only, however, and in the season chosen by Tolchel'nikov for measurement (beginning of May) the takyrs probably were still moist.

21 Roman numerals are the reporters' numbering, arabic numerals Tolchel'nikov's.

22 After the completion of this report the authors received the following book: J.A. Zajcev and L.A. Mukhina, "Primenenie cvetnoj i spektrozonal'noj aerofotos-emki v geologicheskikh celjakh" (The application of color and false color air photography for geological purposes), 303 pp., Izd. Moskovskogo Universiteta, Moscow 1966. This publication includes a comprehensive study on the spectral properties of various rocks and minerals and contains tables and graphs for approx. 500 samples (data usually between 400 and 800 m u). A description of the spectrophotometer SF-4 is also provided.

COLLECTION OF SPECTRAL REFLECTANCE DATA: COMPUTER-GENERATED DIAGRAMS AND TABLES

The following diagrams and tables show reflectance data for wavelengths between 400 and 900 mμ. The ordinate of the diagrams is a logarithmic scale. One diagram contains a maximum of three spectral curves. The corresponding tabulated values are given on the opposite pages. The numbers at the top of the diagrams were used for internal reference during the compilation phase and are not referred to in this report. Explanations to each curve are provided at the bottom of the table pages and are listed in the following order:

Type of object, characteristics: A = age, H = height in m, D = diameter in cm, S = site class, B = density (Russ.: "polnota"[10]); an asterisk stands for a colon /

Type of measurement: L = in the laboratory, G = in the field on the ground, P = from a plane; I = type of instrument: 1 Universal Photometer FM, 2 = photoelectric field spectrometer, 3 = Aerial Spectrograph LS-3, 5 = Aerial Spectrograph LS-2, 6 = Spectrophotometer SF-4, 7 = Spectrovisor (1958), 10 = Spectrometer with a barrier-layer cell (a number in parentheses indicates that the given instrument was used to a minor extent only or that its use is probable but not certain); DM = direction of measurement: the first figure indicates the angle of tilt (deviation from the vertical), the second the azimuth of the sun (0 = measurement against the sun, 180 = measurement away from the sun, 90 = measurement in a plane perpendicular to the shadow direction; DM 0 means measurement in the nadir direction) /

Date (parentheses indicate uncertainty); SA = solar altitude in ^{o} / Location /

Source: Alphameric codes referring to the bibliography (additional sources with the same type of information given in parentheses). "Id." means that the details, except those specified, are the same as for the foregoing curve.

WAVE-LENGTH MMICR.	DIAGRAM 1 NO.1	DIAGRAM 1 NO.2	DIAGRAM 1 NO.3	DIAGRAM 2 NO.1	DIAGRAM 2 NO.2	DIAGRAM 2 NO.3	DIAGRAM 3 NO.1	DIAGRAM 3 NO.2	DIAGRAM 3 NO.3
400	•	•	•	•	•	•	•	•	•
430	•	•	•	•	•	•	•	•	•
450	7.5	4.1	4.7	4.8	4.4	3.7	3.5	2.5	3.0
470	7.9	4.0	4.7	5.3	4.4	3.4	3.0	2.2	2.7
490	8.1	4.0	5.0	6.0	4.5	3.5	3.2	2.2	2.7
510	10.5	4.8	6.1	7.0	5.0	4.2	3.8	2.8	3.2
530	13.8	8.2	8.2	7.9	6.1	5.6	4.9	4.0	4.6
550	14.2	9.0	9.5	8.3	7.1	6.6	6.0	5.1	5.6
570	13.4	7.1	7.9	7.8	6.2	5.6	5.6	4.3	5.0
590	12.7	6.0	6.5	7.0	5.3	4.3	4.4	3.2	3.8
610	12.5	6.2	5.9	6.2	5.3	3.9	4.4	2.9	3.3
630	11.9	5.5	5.0	5.8	5.4	3.8	4.4	2.8	3.3
650	11.1	4.7	4.2	5.5	4.8	3.5	4.2	2.7	3.2
670	10.7	5.0	3.0	5.8	5.1	3.5	4.4	2.6	3.0
690	12.4	9.0	3.7	8.3	7.7	5.8	7.0	4.0	3.7
710	25.5	24.0	19.5	15.9	15.5	13.4	14.4	10.7	9.0
730	59.8	39.5	32.6	28.5	25.2	21.0	22.4	17.6	15.8
750	62.8	44.6	36.1	34.4	28.7	25.7	25.8	20.4	18.9
770	63.0	45.0	37.0	35.4	29.9	26.8	25.0	20.8	19.2
790	63.0	45.1	37.6	35.6	30.4	27.1	25.7	20.8	19.7
810	63.2	45.5	38.4	35.8	30.8	27.2	25.8	20.5	20.1
830	63.3	46.0	38.5	36.0	31.1	27.4	26.1	20.3	20.6
850	63.3	46.2	38.7	36.0	31.4	27.4	26.3	20.5	21.1
870	63.3	46.7	38.9	36.0	31.6	27.4	26.6	20.7	21.3
890	63.4	47.0	39.1	36.0	31.6	27.3	26.7	20.8	21.4

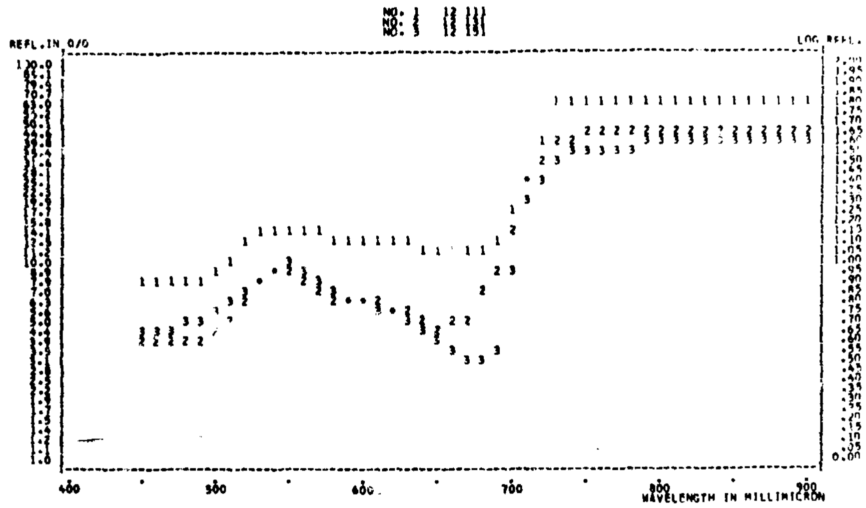
DIAGRAM 1
NO.1 SCOTCH PINE YOUNG SHOOTS (TREE * A 60, H 20, D 44, STAND * S I, B 0.8) / G, I 2,(1) / JUNE 20, 1958, SA 56 / L,VOV / ALEKVA60SDP
NO.2 ID. AUGUST 1, 1958, SA 57
NO.3 ID. OCTOBER 12, 1958, SA 31

DIAGRAM 2
NO.1 SCOTCH PINE 1 TO 2 YEARS OLD SHOOTS (DETAILS AS FOR DIAG. 1) / G, I 2,(1) / JUNE 8, 1958, SA 50 / L,VOV / ALEKVA60SDP
NO.2 ID. JUNE 20, 1958, SA 55
NO.3 ID. JULY 16, 1958, SA 53

DIAGRAM 3
NO.1 SCOTCH PINE 1 TO 2 YEARS OLD SHOOTS (DETAILS AS FOR DIAG. 1) / G, I 2,(1) / AUGUST 1, 1958, SA 57 / L,VOV ALEKVA60SDP
NO.2 ID. SEPTEMBER 15, 1958, SA 42
NO.3 ID. OCTOBER 12, 1958, SA 31

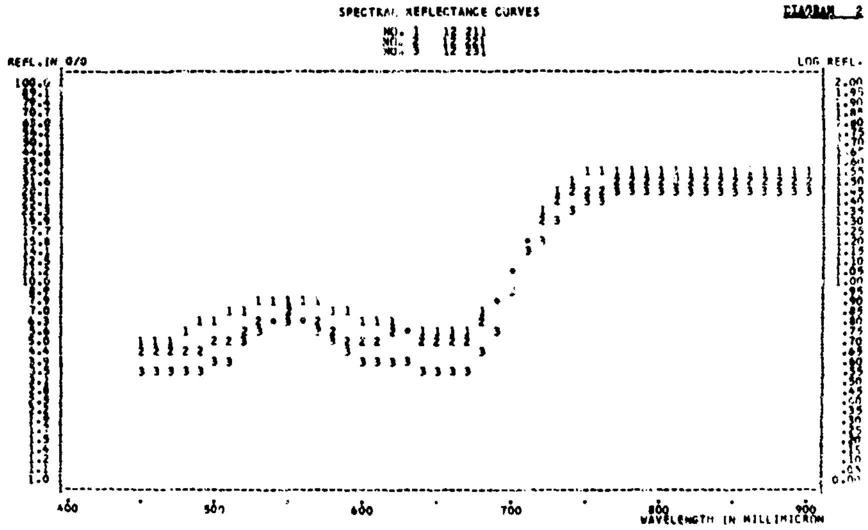
SPECTRAL REFLECTANCE CURVES

DIAGRAM 1



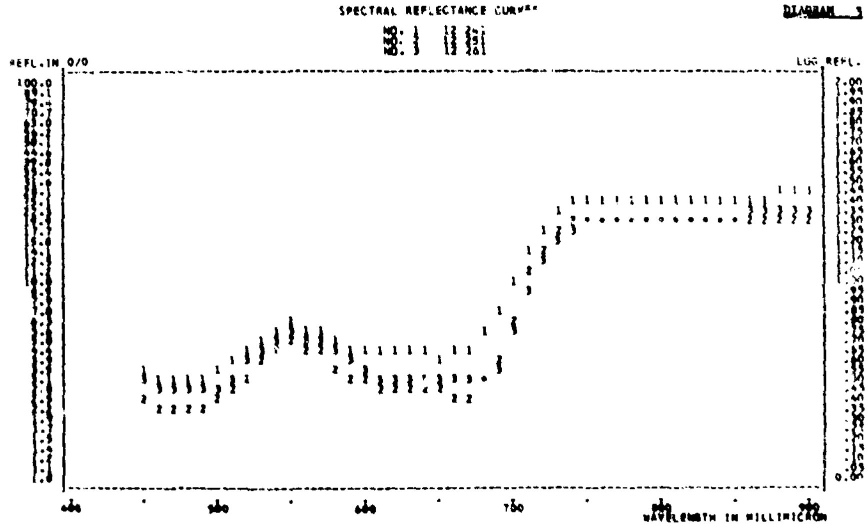
SPECTRAL REFLECTANCE CURVES

DIAGRAM 2



SPECTRAL REFLECTANCE CURVES

DIAGRAM 3



WAVE-LENGTH MMICR.	DIAGRAM 4 NO.1	NO.2	NO.3	DIAGRAM 5 NO.1	NO.2	NO.3	DIAGRAM 6 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	.	.	.	.	.	.	3.2	.	.
450	7.5	3.9	2.6	4.9	2.5	1.6	3.8	2.9	1.3
470	7.6	4.4	2.7	4.6	2.4	1.3	4.1	2.5	1.3
490	8.0	5.0	2.9	4.3	2.5	.8	5.2	3.1	1.5
510	10.0	6.7	3.7	5.7	3.5	1.6	10.1	4.8	2.7
530	14.4	10.5	5.1	7.5	5.0	3.0	14.5	7.4	4.3
550	15.4	11.7	6.7	7.5	5.6	3.8	15.0	7.9	4.8
570	14.[illegible]	10.4	5.4	6.8	4.8	3.1	15.0	7.4	4.2
590	12.4	8.7	4.4	6.3	4.5	2.6	11.4	6.1	3.5
610	10.8	7.7	4.1	6.1	4.5	2.1	10.5	4.6	3.0
630	9.4	7.1	4.0	5.6	4.3	2.0	9.9	3.8	2.7
650	8.7	7.0	3.6	4.7	4.1	2.1	6.7	3.7	2.7
670	1[illegible].6	8.4	3.5	4.6	3.5	2.4	6.6	4.1	3.1
690	23.[illegible]	16.[illegible]	7.8	9.9	6.6	4.4	8.3	4.8	3.6
710	48.0	36.	21.2	19.7	16.1	10.6	.	.	.
730	63.0	51.0	36.3	27.2	23.0	18.2	.	.	.
750	64.5	55.2	41.0	30.2	26.1	20.8	.	.	.
770	65.0	56.5	41.9	30.5	26.6	21.2	.	.	.
790	65.0	57.0	42.2	30.6	27.2	21.5	.	.	.
810	65.0	57.2	43.6	30.6	27.4	22.6	.	.	.
830	64.8	57.4	44.1	30.8	27.5	22.8	.	.	.
850	64.7	57.5	44.3	30.9	27.7	22.9	.	.	.
870	64.7	57.[illegible]	45.1	31.0	28.0	23.5	.	.	.
890	64.8	57.7	44.8	31.1	28.1	23.3	.	.	.

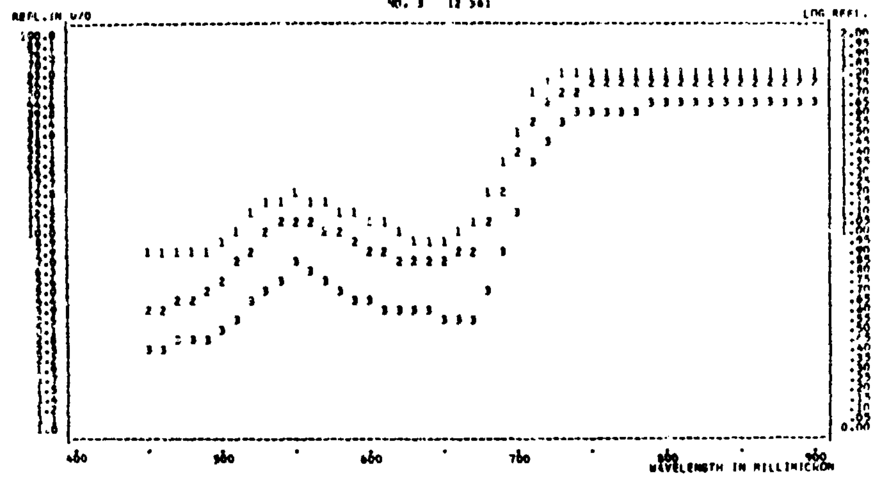
DIAGRAM 4
NO.1 NORWAY SPRUCE YOUNG SHOOTS (TREE * A 60, H 22, D 38)
G, I 2,(1) / JUNE 7, 1958, SA 61 / L,VOV / ALEKVA60SDP
NO.2 ID. JULY 31, 1958, SA 49
NO.3 ID. SEPTEMBER 29, 1958, SA 29

DIAGRAM 5
NO.1 NORWAY SPRUCE 1 TO 2 YEARS OLD SHOOTS (DETAILS AS
FOR DIAG. 4) / G, I 2,(1) / JUNE 7, 1958, SA 61 /
L,VOV / ALEKVA60SDP
NO.2 ID. JULY 31, 1958, SA 49
NO.3 ID. SEPTEMBER 29, 1958, SA 30

DIAGRAM 6
NO.1 SPRUCE YOUNG NEEDLES, (STAND * A 100 TO 120,
S III, B 0.7) / G, I 1 / JUNE 22, 1955 / LENINGRAD /
ARCYES58OSD, 'BELOSV59AFL)
NO.2 ID. JULY 6, 1955
NO.3 ID. SEPTEMBER 9, 1955

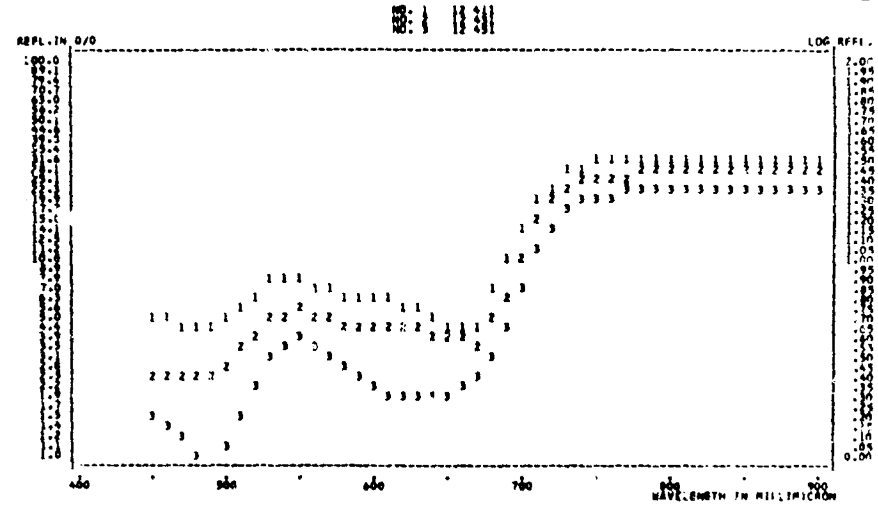
SPECTRAL REFLECTANCE CURVES

DIAGRAM 4



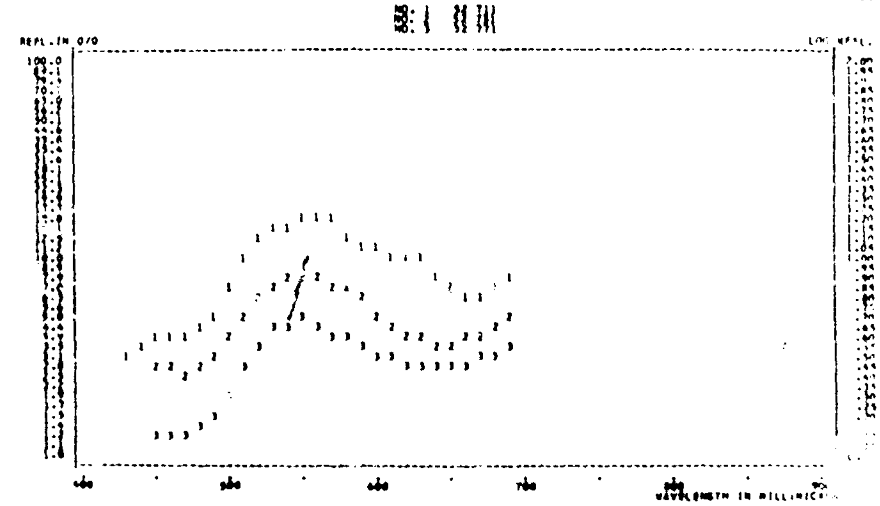
SPECTRAL REFLECTANCE CURVES

DIAGRAM 5



SPECTRAL REFLECTANCE CURVES

DIAGRAM 6



WAVE-LENGTH λ.	DIAGRAM 7 NO.1	NO 2	NO.3	DIAGRAM 8 NO.1	NO.2	NO.3	DIAGRAM 9 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	1.2	.9	.
430	1.2	.	.	.	.	.	1.2	.9	.
450	1.5	2.0	1.0	.8	1.5	.	1.3	1.0	.
470	1.5	1.8	1.0	.9	1.4	.	1.9	1.4	.
490	1.7	2.3	1.1	1.1	1.7	.	2.8	2.1	.
510	3.0	3.7	1.5	1.5	2.3	.	4.2	3.3	.
530	4.1	5.1	2.1	2.1	2.8	.	6.7	5.0	.
550	4.3	5.0	2.1	2.5	3.2	.	7.8	5.7	.
570	3.9	4.5	1.8	2.3	3.1	.	6.8	4.9	.
590	3.0	3.8	1.5	2.0	2.8	.	5.9	4.2	.
610	2.3	3.2	1.3	1.5	2.2	.	5.0	3.9	.
630	2.2	2.9	1.2	1.2	1.9	.	4.5	3.8	.
650	2.5	2.9	1.4	1.4	2.0	.	4.5	3.8	.
670	2.9	3.3	1.6	1.8	2.4	.	4.8	4.0	.
690	3.4	4.0	1.9	2.2	2.6	.	.	.	.
710	.	.	.	.	.	.	.	.	.
730	.	.	.	.	.	.	.	.	.
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

DIAGRAM 7

NO.1 SPRUCE OLD NEEDLES, (STAND * A 100 TO 120, S III, B 0.7) / G, I 1 / JUNE 22, 1955 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)

NO.2 ID. JULY 6, 1955

NO.3 ID. SEPTEMEBR 9, 1955

DIAGRAM 8

NO.1 SPRUCE, NEEDLES FROM UPPER PART OF CROWN,(STAND * A 90, S III, B 0.7, BILBERRY SPRUCE FOREST) / G, I 1 / SEPTEMBER 9, 1955 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)

NO.2 ID. FROM LOWER PART OF CROWN

DIAGRAM 9

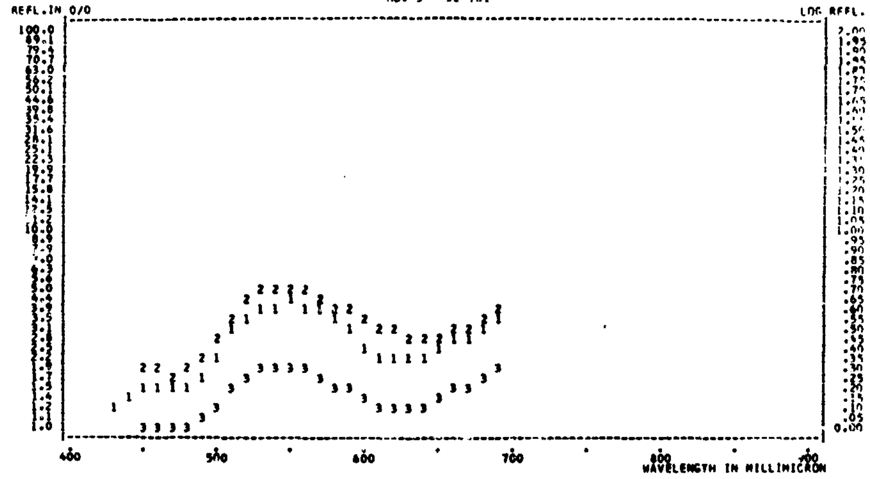
NO.1 NORWAY SPRUCE NEEDLES FROM UNDERSTORY TREE / G, I 1 / JULY 10 TO 12, 1956 / ARKHANGELSK / KHARNG60AIT

NO.2 ID. NEEDLES FROM OVERSTORY TREE

SPECTRAL REFLECTANCE CURVES

DIAGRAM 7

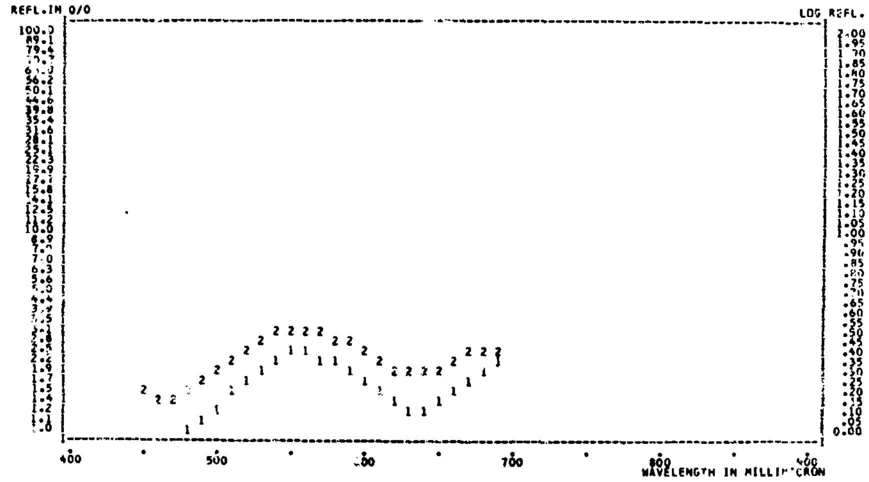
NO: 1 52 721
NO: 2 52 741
NO: 3 52 761



SPECTRAL REFLECTANCE CURVES

DIAGRAM 8

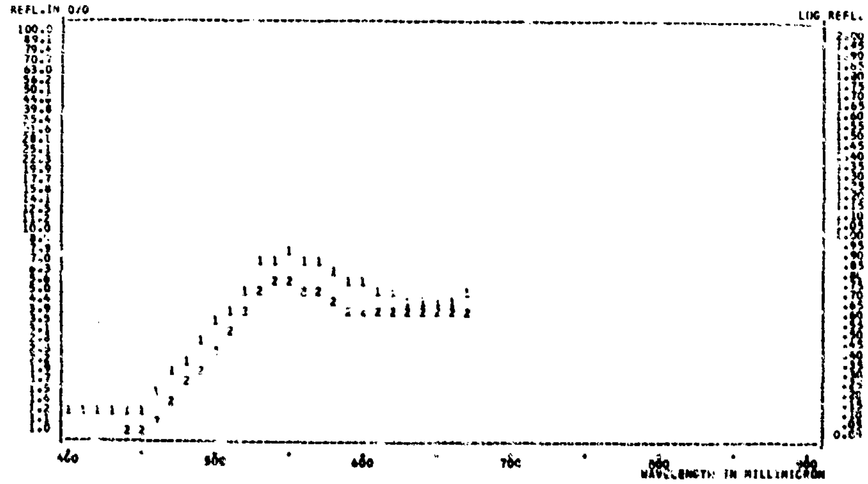
NO: 1 52 831
NO: 2 52 841



SPECTRAL REFLECTANCE CURVES

DIAGRAM 9

NO: 1 53 231
NO: 2 53 241



WAVE-LENGTH MMICR.	DIAGRAM 10 NO.1	NO.2	NO.3	DIAGRAM 11 NO.1	NO.2	NO.3	DIAGRAM 12 NO.1	NO.2	NO.3
400	.	.	.	2.0	2.6	6.0	5.5	3.4	.
430	.	.	.	2.0	3.0	6.4	5.4	3.6	.
450	.	.	.	2.3	3.3	6.8	5.5	4.0	.
470	.	.	.	2.5	3.7	7.3	6.0	5.0	.
490	.	.	.	3.0	3.9	8.0	6.9	6.2	.
510	.	.	.	3.6	4.9	9.5	8.1	8.7	.
530	.	.	.	4.7	7.7	13.6	14.0	12.2	.
550	4.3	4.5	.	6.0	9.3	14.4	16.0	13.2	.
570	3.5	3.7	.	5.7	8.0	12.7	14.7	10.7	.
590	2.8	2.8	.	5.0	6.8	10.5	13.0	8.3	.
610	2.3	2.3	.	4.6	5.9	9.1	11.8	8.0	.
630	2.0	2.2	.	4.3	5.3	8.4	12.0	8.0	.
650	1.6	2.2	.	4.0	5.0	7.7	12.3	8.2	.
670	1.4	1.7	.	4.5	5.2	8.8	12.7	8.5	.
690	2.0	2.2	.	7.5	11.5	19.2	13.2	9.3	.
710	7.0	8.5	.	25.0	28.9	49.0	.	.	.
730	29.3	28.1	.	40.5	44.4	54.5	.	.	.
750	36.6	32.2	.	46.[illegible]	52.0	57.5	.	.	.
770	.	.	.	47.[illegible]	52.8	58.8	.	.	.
790	.	.	.	48.0	53.2	59.0	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

DIAGRAM 10
NO.1 STAND OF SCOTCH PINE A 30, (FOR DETAILS SEE TABLE 6, PLOT 1) / P, I 3, DM 0 / JULY 11, 1958, SA 54 / LVOV / ALEKVA60SDP
NO.2 ID. A 110 (FOR DETAILS SEE TABLE 6, PLOT 5)

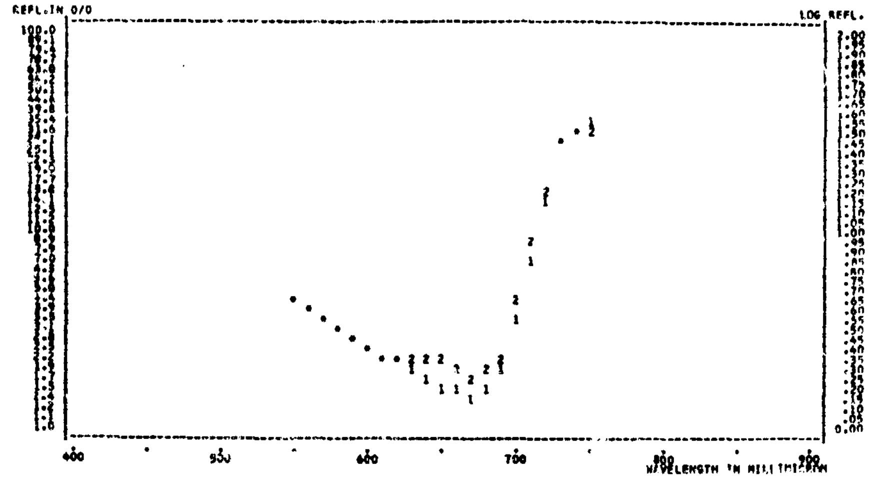
DIAGRAM 11
NO.1 SCOTCH PINE WHOLE CROWN (STAND * A 40, S II, B 0.5) / G, I 1,3, AVERAGE OF 2 TREES / AUGUST 3 TO 7, 1957, SA 46 / TOMSK / BELOSV59AFL
NO.2 ID. OLD SHOOTS (1 TO 2 YEARS OLD) / SA 47
NO.3 ID. YOUNG SHOOTS / SA 47

DIAGRAM 12
NO.1 PINE, NEEDLES FROM NORTHERN PART OF CROWN, (TREE * A 70, IN BILBERRY PINE FOREST) / G, I 1 / AUGUST 9, 1956, SA 30 / ARKHANGELSK / BELOSV59AFL
NO.2 ID. FROM SOUTHERN PART OF CROWN

SPECTRAL REFLECTANCE CURVES

DIAGRAM 10

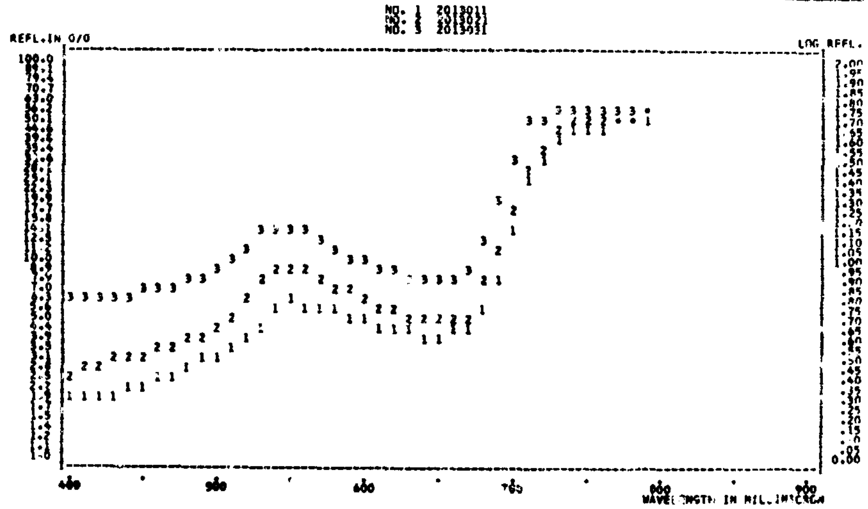
NO. 1 [illegible]
NO. 2 [illegible]



SPECTRAL REFLECTANCE CURVES

DIAGRAM 11

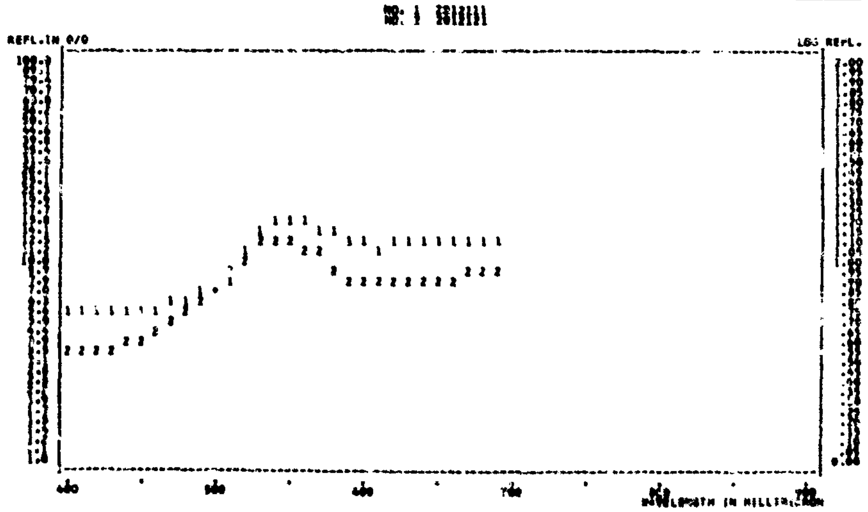
NO. 1 2013011
NO. 2 2013021
NO. 3 2013031



SPECTRAL REFLECTANCE CURVES

DIAGRAM 12

NO. 1 [illegible]
NO. 2 [illegible]



WAVE-LENGTH MMICR.	DIAGRAM 13 NO.1	NO.2	NO.3	DIAGRAM 14 NO.1	NO.2	NO.3	DIAGRAM 15 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	3.1	3.1	1.2	.	.	.	.	.	.
450	3.7	3.2	1.5	3.3	3.6	3.9	6.0	6.6	5.7
470	4.1	3.7	1.5	3.7	3.8	3.8	6.8	6.8	6.1
490	5.1	4.7	1.8	4.5	4.0	4.0	8.0	7.4	6.9
510	11.3	7.9	2.7	6.0	5.2	4.6	9.8	9.3	8.7
530	14.9	13.1	4.0	7.5	6.7	5.4	13.0	12.2	11.5
550	15.2	13.5	4.4	8.8	7.7	6.0	16.5	14.2	12.9
570	15.0	10.7	3.9	8.8	7.2	5.7	17.0	13.2	12.2
590	11.4	9.3	3.0	8.2	6.4	5.3	15.6	11.7	10.9
610	10.5	8.0	2.4	7.1	5.6	4.8	13.3	9.9	9.4
630	10.0	6.8	2.3	6.2	5.1	4.4	11.2	8.3	8.0
650	6.9	6.1	2.4	6.0	5.0	4.3	10.7	7.9	7.7
670	6.9	5.7	2.7	6.4	5.4	4.4	11.5	8.7	8.3
690	8.5	.	.	7.0	6.0	4.5	12.7	9.6	9.2
710	.	.	.	.	.	.	.	.	.
730	.	.	.	.	.	.	.	.	.
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

DIAGRAM 13

NO.1 SPRUCE YOUNG NEEDLES / G, I 1 / JUNE 21, 1955 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)

NO.2 BIRCH YOUNG LEAVES, LIGHT GREEN / G, I 1 / JUNE 21, 1955 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)

NO.3 SPRUCE OLD NEEDLES / G, I 1 / JUNE 21, 1955 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)

DIAGRAM 14

NO.1 SCOTCH PINE 1 TO 2 YEARS OLD SHOOTS, (STAND * PEAT-MOSS PINE FOREST, A 120 TO 140, S V) / G, I 1, AVERAGE OF 5 TREES / JUNE 20 TO 23, 1955, SA 47 TO 51 / LENINGRAD BELOSV59AFL

NO.2 ID. (STAND * BILBERRY PINE FOREST, A 120, S III) / JUNE 21 TO 29, 1955

NO.3 ID. (STAND * WOOD-SORREL PINE FOREST, A 120, S II) / AVERAGE OF 2 TREES / JUNE 20 TO 27, 1955, SA 45 TO 47

DIAGRAM 15

NO.1 BIRCH (STAND * PEAT-MOSS BIRCH FOREST, A 100, S V) / G, I 1 , AVERAGE OF 3 MEASUREMENTS / JUNE 20 TO JULY 1, 1955, SA 46 TO 48 / LENINGRAD / BELOSV59AFL

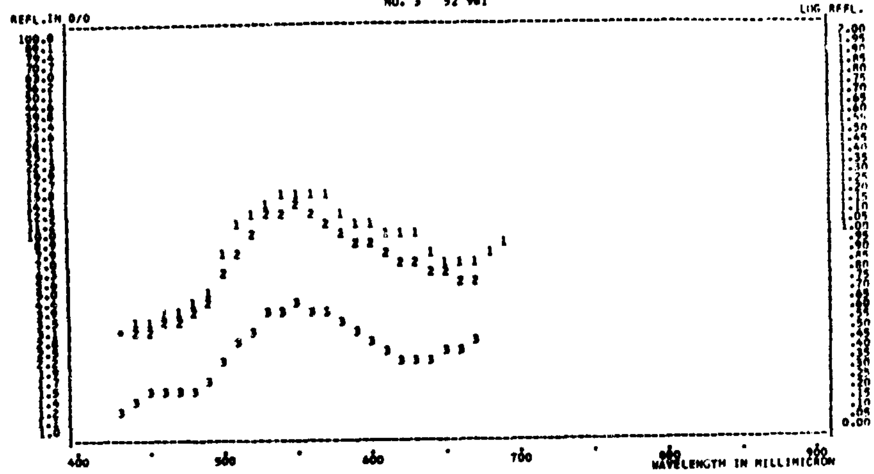
NO.2 ID. (STAND * BILBERRY BIRCH FOREST, A 30 TO 100, S III) / AVERAGE OF 5 MEASUREMENTS / JUNE 23 TO 28, 1955, SA 46 TO 51

NO.3 ID. (STAND * WOOD-SORREL BIRCH FOREST, A 80 TO 90, S I TO II) / AVERAGE OF 5 MEASUREMENTS / JUNE 25 TO 30, 1955, SA 46 TO 51

SPECTRAL REFLECTANCE CURVES

DIAGRAM 13

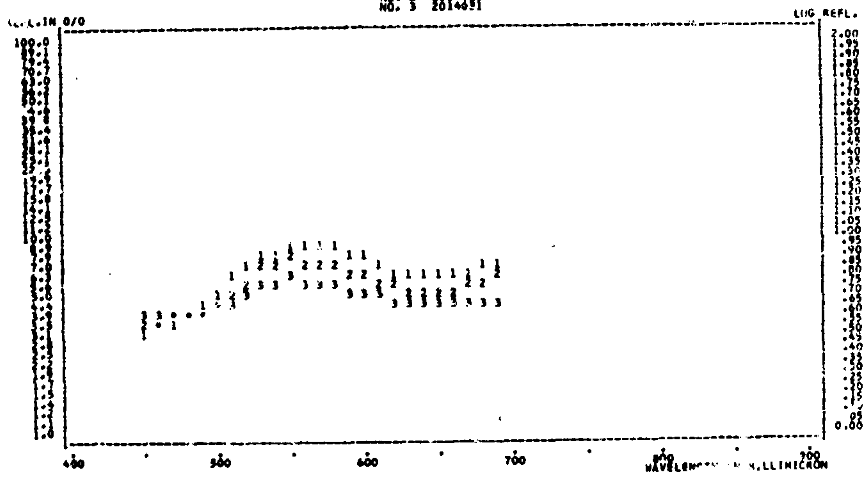
NO: 1 [illegible]
NO: 2 [illegible]
NO: 3 [illegible]



SPECTRAL REFLECTANCE CURVES

DIAGRAM 14

NO: 1 2014611
NO: 2 [illegible]
NO: 3 [illegible]



SPECTRAL REFLECTANCE CURVES

DIAGRAM 15

NO: 1 [illegible]
NO: 2 [illegible]
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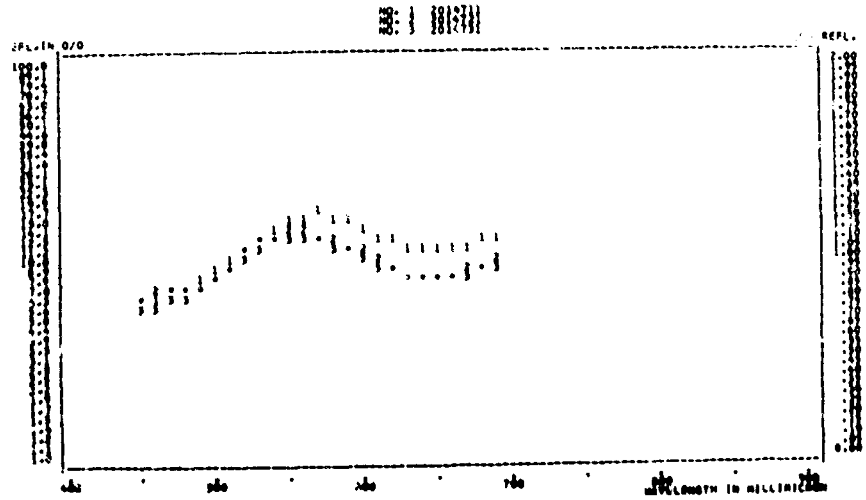


WAVE-LENGTH MMICR.	DIAGRAM 16 NO.1	DIAGRAM 16 NO.2	DIAGRAM 16 NO.3	DIAGRAM 17 NO.1	DIAGRAM 17 NO.2	DIAGRAM 17 NO.3	DIAGRAM 18 NO.1	DIAGRAM 18 NO.2	DIAGRAM 18 NO.3
400	.	.	.	.	.	.	.	.	.
430	.	.	.	.	.	.	.	.	.
450	6.5	4.0	4.9	3.0	4.0	.	8.3	4.2	8.8
470	5.8	2.6	4.2	3.1	3.6	.	8.8	4.5	9.2
490	5.0	2.4	3.8	2.9	3.3	.	9.6	4.3	9.8
510	6.5	4.0	5.0	3.1	6.5	3.2	11.5	5.5	13.8
530	11.8	7.3	8.8	6.5	12.7	3.6	15.4	8.5	23.8
550	13.5	9.2	10.5	8.2	17.8	4.5	17.5	10.5	32.6
570	10 7	8.0	9.0	7.2	22.6	5.8	15.5	10.1	40.0
590	8.3	6.8	7.5	5.8	25.1	7.7	14.0	8.7	42.3
610	7.1	5.8	6.5	4.9	25.4	8.7	13.5	6.8	42.0
630	6.7	5.4	6.0	4.7	24.7	9.4	12.4	6.7	43.5
650	6.4	4.6	5.3	3.8	23.3	9.8	10.9	6.3	43.5
670	6.6	4.4	5.5	3.3	22.5	10.7	11.8	5.4	43.2
690	12.5	9.8	9.3	6.4	26.5	12.5	21.5	7.6	46.0
710	43.5	39.5	32.2	19.8	36.6	15.5	53.5	19.4	49.8
730	70.2	65.2	56.9	32.0	40.5	17.9	73.2	30.0	52.1
750	79.0	69.5	61.3	37.2	43.0	18.1	78.2	34.3	53.2
770	80.8	71.1	63.2	38.0	45.3	18.5	79.8	36.4	54.2
790	79.8	72.6	64.1	39.3	47.6	19.8	80.2	37.5	55.6
810	79.8	73.3	65.0	39.7	49.5	21.3	80.2	38.4	56.8
830	81.0	73.9	65.2	40.0	50.9	23.0	80.3	39.4	57.8
850	82.0	73.8	65.4	40.5	52.0	24.3	80.3	39.8	58.3
870	82.1	74.0	66.2	41.0	53.0	25.3	80.4	40.2	58.7
890	82.0	74.1	67.2	41.3	53.5	25.8	80.4	40.4	58.7

DIAGRAM 16

NO.1 BEECH GREEN LEAVES (TREE * A 30, H 17, D 30) / G, I 2,(1) / JULY 16, 1958 SA 60 / L,VOV / ALEKVA60SDP

NO.2 ID. JULY 31, 1958, SA 58

NO.3 ID. SEPTEMBER 14, 1958, SA 43

DIAGRAM 17

NO.1 BEECH GREEN LEAVES (DETAILS AS FOR DIAG. 16) / G, I 2,(1) / SEPTEMBER 29, 1958, SA 36 / L,VOV / ALEKVA60SDP
1958, SA 36 / L,VOV / ALEKVA60SDP

NO.2 ID. YELLOW-ORANGE LEAVES / OCTOBER 1, 1958, SA 35

NO.3 ID. DRY LEAVES, GRAY-BROWN / OCTOBER 11, 1958, SA 32

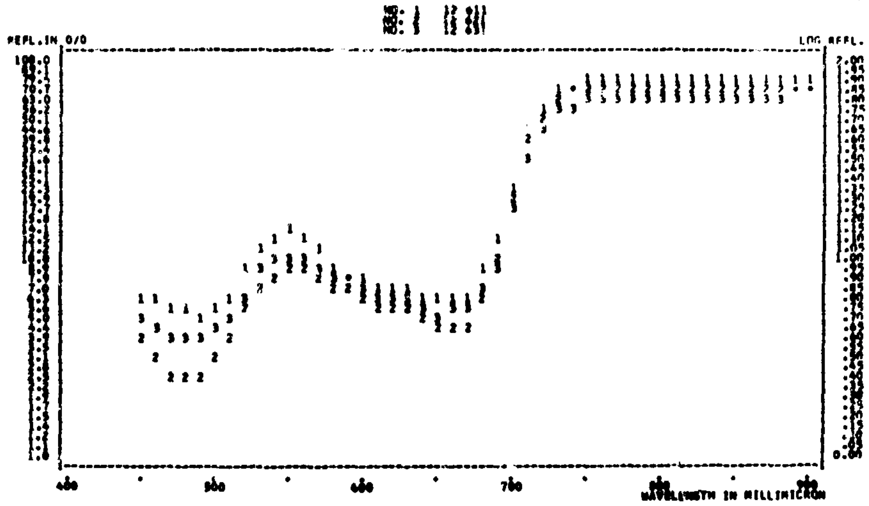
DIAGRAM 18

NO.1 EUROPEAN WHITE BIRCH GREEN LEAVES (TREE * A 55, H 23, D 25) / G, I 2,(1) / JUNE 17, 1958, SA 43 / L,VOV / ALEKVA60SDP

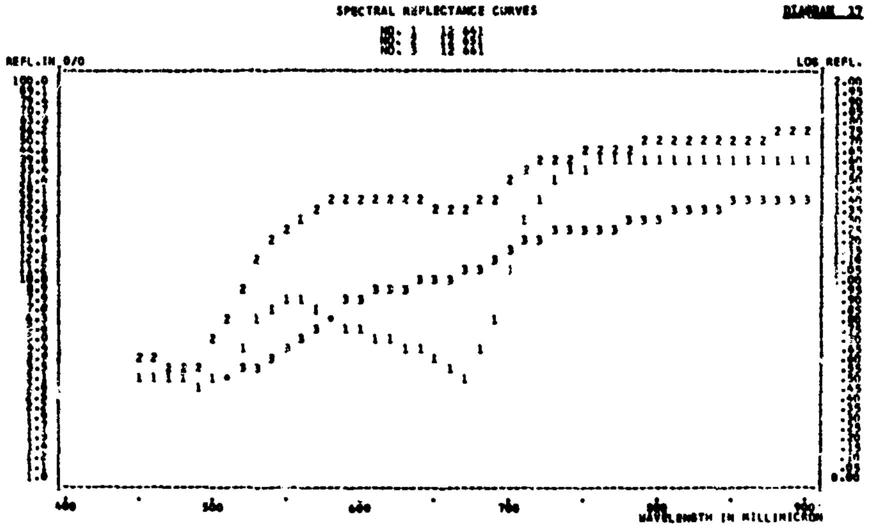
NO.2 ID. SEPTEMBER 30, 1958, SA 36

NO.3 ID. YELLOW LEAVES / OCTOBER 11, 1958, SA 34

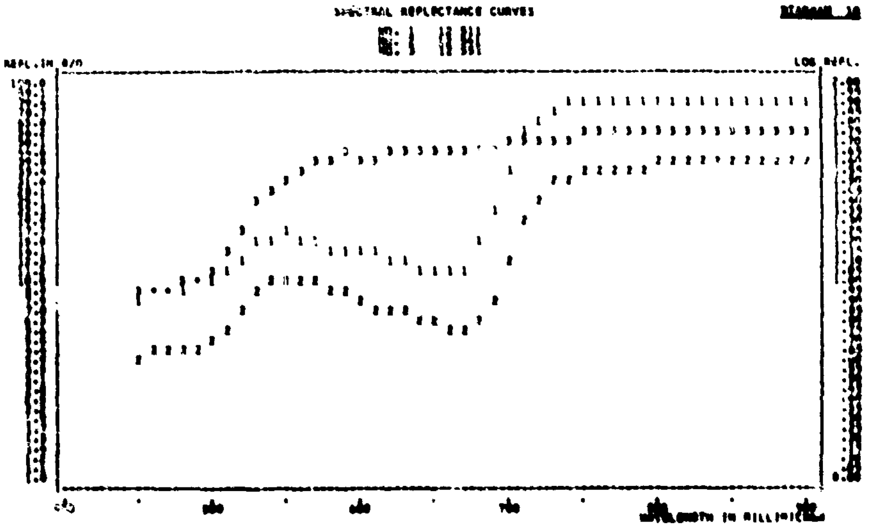
SPECTRAL REFLECTANCE CURVES DIAGRAM 16



SPECTRAL REFLECTANCE CURVES DIAGRAM 17



SPECTRAL REFLECTANCE CURVES DIAGRAM 18



WAVE-LENGTH MMICR.	DIAGRAM 19 NO.1	DIAGRAM 19 NO.2	DIAGRAM 19 NO.3	DIAGRAM 20 NO.1	DIAGRAM 20 NO.2	DIAGRAM 20 NO.3	DIAGRAM 21 NO.1	DIAGRAM 21 NO.2	DIAGRAM 21 NO.3
400	.	5.0	7.3	.	.	.	.	.	.
430	.	5.4	7.2	.	.	.	.	.	.
450	.	5.4	7.6	.	.	.	.	.	.
470	.	5.3	8.2	.	.	.	.	.	.
490	.	5.2	10.5	7.8	.	.	.	.	.
510	.	5.1	18.3	8.5	9.3	10.7	18.5	17.2	.
530	.	5.0	29.2	10.7	19.4	25.0	20.2	23.0	.
550	19.2	5.6	34.2	14.2	24.3	28.8	22.5	27.6	.
570	15.2	8.2	36.2	12.1	24.5	33.0	25.0	31.0	.
590	12.4	24.0	38.0	10.6	20.2	36.4	27.6	32.5	.
610	11.0	36.8	39.5	9.7	18.4	38.0	29.7	31.2	.
630	10.0	47.0	40.6	8.5	16.0	39.5	30.8	29.4	.
650	8.6	49.0	42.0	7.5	14.0	41.7	35.5	29.8	.
670	7.5	52.0	43.4	6.2	9.8	43.5	33.8	24.0	.
690	22.0	69.0	45.0	7.7	10.8	45.0	35.8	27.3	.
710	50.0	72.0	47.5	26.0	32.0	46.7	43.5	47.2	.
730	79.0	73.0	51.4	33.1	45.0	49.0	45.0	64.0	.
750	84.8	73.5	56.4	.	.	.	47.0	67.3	.
770	85.1	74.0	58.0	.	.	.	50.0	69.0	.
790	85.2	74.0	58.0	.	.	.	52.3	70.5	.
810	.	.	.	.	.	.	54.7	71.5	.
830	.	.	.	.	.	.	55.7	72.0	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

DIAGRAM 19

NO.1 ASPEN GREEN LEAVES, (STAND • A 30, S III, B 0.5) G, I 3,(1) / AUGUST 25, 1957, SA 42 / TOMSK / BELOSV59AFL

NO.2 ID. RED LEAVES, (TREE • A 40) / SEPTEMBER 12, 1957, SA 37

NO.3 ID. YELLOW LEAVES, (TREE • A 40) / SEPTEMBER 12, 1957, SA 37

DIAGRAM 20

NO.1 MAPLE, LEAVES GREEN / PRONAK49IRA (AFTER N.E. VEDENEEVA)

NO.2 ID. GREEN-YELLOW

NO.3 ID. YELLOW

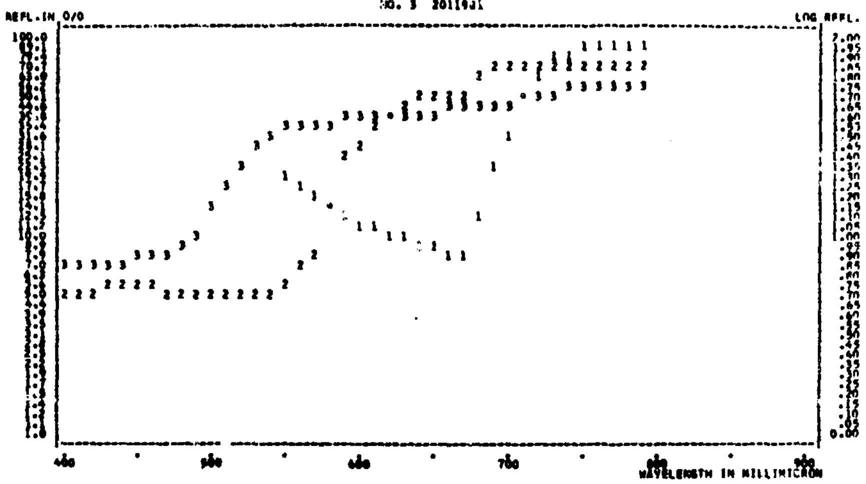
DIAGRAM 21

NO.1 LARCH, NEEDLES YELLOW / I 6 / WESTERN YAKUTIA / BAKHVM60MSA (AFTER Z.L. PETRUSHKINA)

NO.2 ID. GREEN

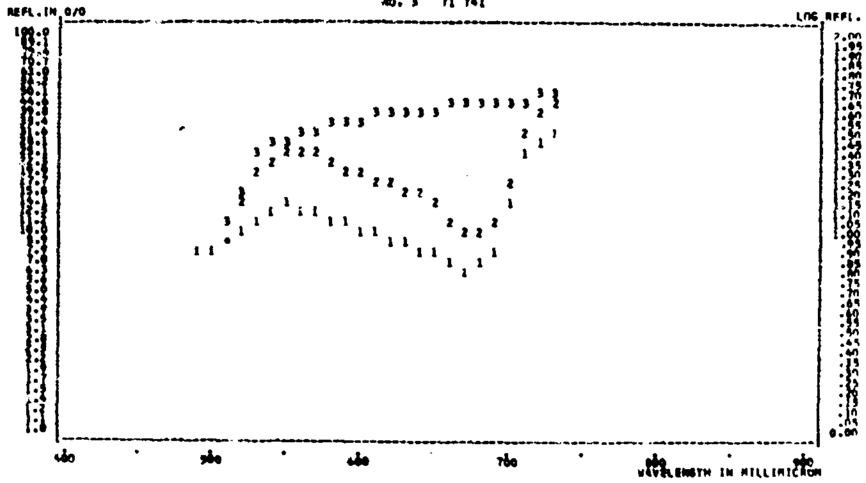
SPECTRAL REFLECTANCE CURVES

DIAGRAM 19



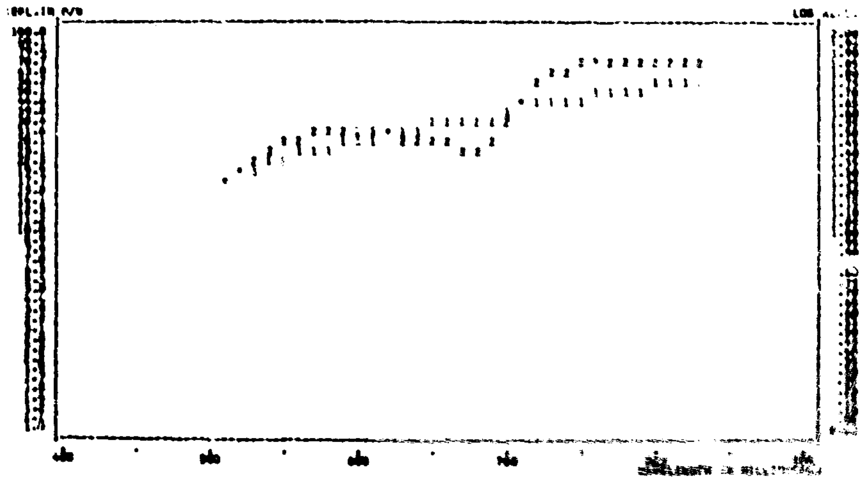
SPECTRAL REFLECTANCE CURVES

DIAGRAM 20



SPECTRAL REFLECTANCE CURVES

DIAGRAM 21



WAVE-LENGTH MMICR.	DIAGRAM 22 NO.1	NO.2	NO.3	DIAGRAM 23 NO.1	NO.2	NO.3	DIAGRAM 24 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	3.8	7.9	.3	2.2	4.1	8.2	.	.	.
450	3.7	8.3	.4	2.5	4.3	9.3	2.0	3.1	.
470	4.2	9.3	.5	2.8	4.8	11.0	1.7	3.3	.
490	5.7	12.0	.7	3.6	6.3	15.4	2.0	3.8	.
510	6.2	15.0	1.0	4.3	8.3	23.1	2.5	4.7	.
530	8.1	17.2	1.2	4.1	10.0	27.1	3.4	6.5	.
550	9.6	18.4	1.1	4.4	11.4	28.5	3.9	6.8	.
570	7.6	15.0	.8	4.3	9.8	25.6	3.6	6.4	.
590	6.3	13.5	.8	4.0	7.0	22.5	3.2	5.8	.
610	6.0	13.4	.8	3.8	6.0	20.7	2.5	4.0	.
630	5.9	13.4	.7	3.6	5.5	19.3	2.1	3.7	.
650	6.0	13.7	.6	3.8	5.2	18.1	2.3	4.2	.
670	6.3	14.0	.5	4.7	5.5	17.7	2.8	4.8	.
690	11.0	15.5	.4	5.4	6.5	19.9	3.2	5.5	.
710	37.6	.	.	10.5	20.6	29.5	.	.	.
730	49.7	.	.	24.5	45.0	66.2	.	.	.
750	50.0	.	.	36.0	56.2	68.7	.	.	.
770	49.7	.	.	37.0	57.0	69.3	.	.	.
790	.	.	.	37.2	58.0	69.5	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

DIAGRAM 22
NO.1 PUBESCENT BIRCH, LEAVES UPPER SIDE (STAND * A 80, S IV) / G, I 1,5 / JULY 6, 1956, SA 45 TO 46 / ARKHANGELSK / BELOSV59AFL
NO.2 ID. LOWER SIDE
NO.3 ID. LOWER SIDE, IN SHADOW

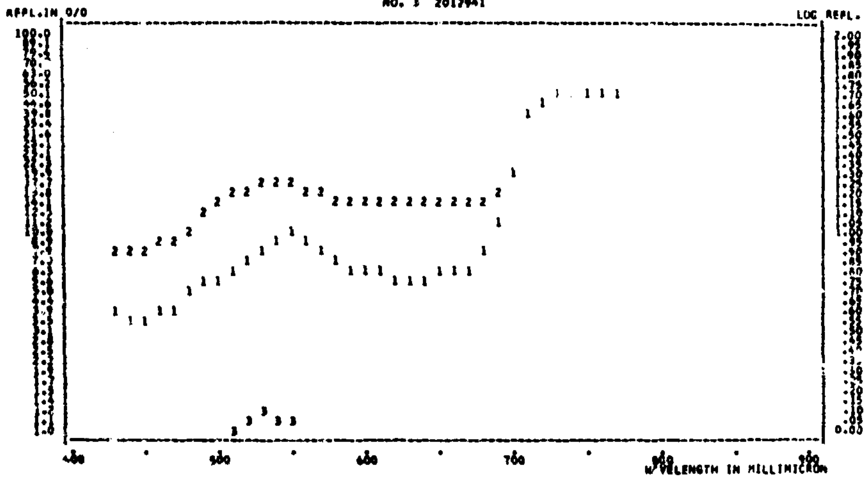
DIAGRAM 23
NO.1 ASPEN, WHOLE CROWN (STAND * A 30, S II) / G, I 1,5 / AUGUST 20, 1956, SA 38 / ARKHANGELSK / BELOSV59AFL
NO.2 ID., LEAVES DARK-GREEN, UPPER SIDE
NO.3 ID. LOWER SIDE

DIAGRAM 24
NO.1 BIRCH, LEAVES GREEN, FROM UPPER PART OF CROWN, (STAND * A 70, S III, B 0.6, BILBERRY BIRCH FOREST) / G, I 1 / SEPTEMBER 9, 1955 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)
NO.2 ID. FROM LOWER PART OF CROWN

SPECTRAL REFLECTANCE CURVES

DIAGRAM 22

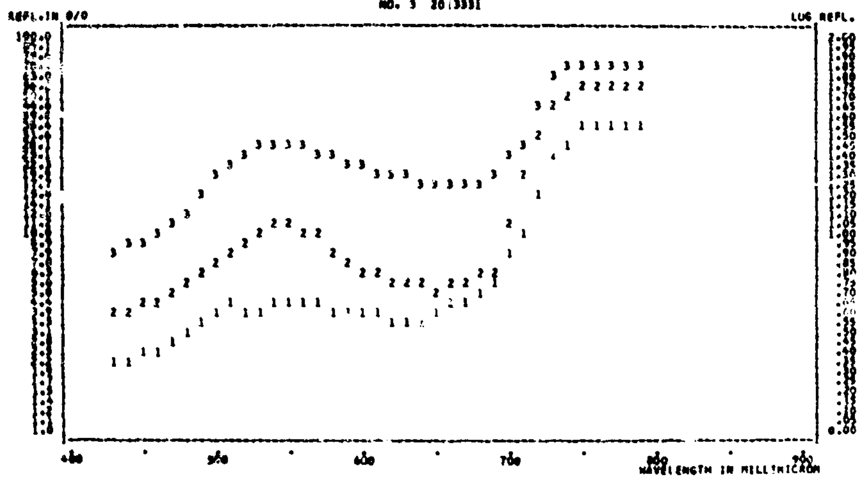
NO: 1 [illegible]
NO: 2 [illegible]
NO: 3 [illegible]



SPECTRAL REFLECTANCE CURVES

DIAGRAM 23

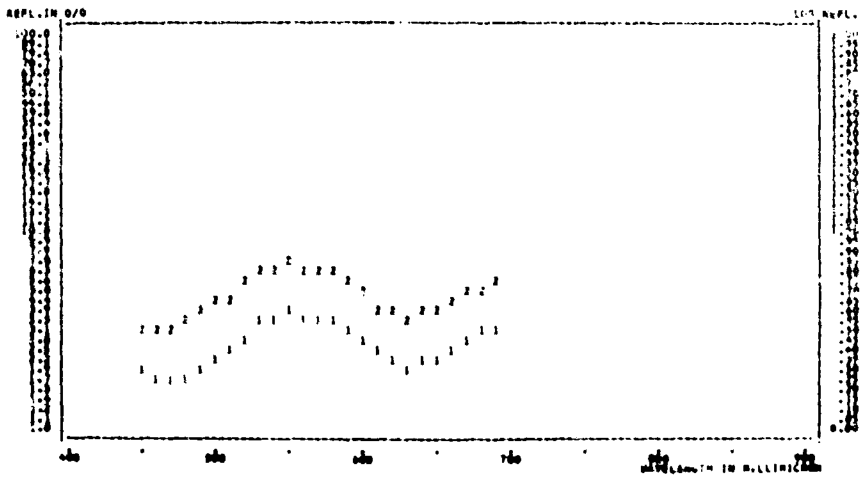
NO: 1 [illegible]
NO: 2 [illegible]
NO: 3 [illegible]



SPECTRAL REFLECTANCE CURVES

DIAGRAM 24

NO: 1 [illegible]
NO: 2 [illegible]



WAVE-LENGTH MMICR.	DIAGRAM 25 NO.1	DIAGRAM 25 NO.2	DIAGRAM 25 NO.3	DIAGRAM 26 NO.1	DIAGRAM 26 NO.2	DIAGRAM 26 NO.3	DIAGRAM 27 NO.1	DIAGRAM 27 NO.2	DIAGRAM 27 NO.3
400	.	.	.	.	.	.	.	.	.
430	.	.	.	.	.	.	.	.	.
450	.	.	.	.	.	.	.	.	.
470	.	.	.	.	.	.	.	.	.
490	.	.	.	.	.	.	.	.	.
510	.	.	.	.	.	.	.	.	.
530	.	.	.	6.2	8.5	6.7	.	.	.
550	6.0	4.3	2.8	6.8	9.2	7.[illegible]	3.8	7.3	2.5
570	4.8	3.5	2.6	5.9	7.9	6.6	3.0	5.4	1.8
590	3.7	2.8	2.1	4.9	6.4	5.4	2.5	4.0	1.5
610	2.9	2.3	1.7	4.6	5.8	5.0	2.3	3.1	1.3
630	2.5	2.0	1.3	4.8	5.6	4.9	2.0	2.9	1.2
650	2.4	1.6	1.2	4.7	5.7	4.4	2.0	2.8	1.1
670	2.3	1.4	1.0	5.2	6.2	5.4	2.1	3.2	1.2
690	2.7	2.0	1.5	7.4	8.5	7.9	3.3	5.4	1.4
710	7.9	7.0	5.1	12.3	15.6	13.9	8.0	11.1	3.7
730	34.7	29.3	22.0	16.6	20.0	16.2	21.3	26.8	12.5
750	39.5	36.6	30.1	17.0	21.1	16.7	32.5	39.8	26.1
770	.	.	.	16.2	20.7	16.1	34.5	41.3	28.1
790	.	.	.	.	.	.	34.6	41.2	28.4
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

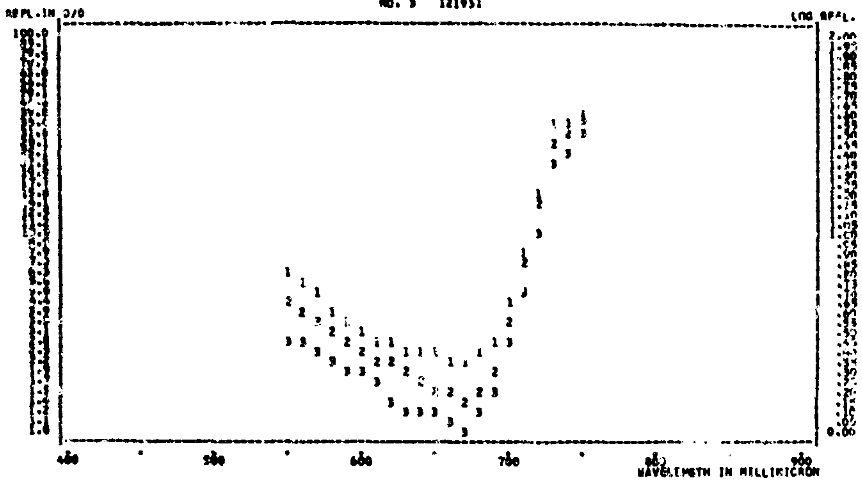
DIAGRAM 25
NO.1 STAND OF SCOTCH PINE (FOR DETAILS SEE TABLE 6, PLOT 1)
P, I 3, DM 30,180 / JULY 11, 1958, SA 54 / L,VOV /
ALEKVA60SDP
NO.2 ID. DM 0
NO.3 ID. DM 30,0

DIAGRAM 26
NO.1 STAND OF SCOTCH PINE MATURE, (FOR DETAILS SEE TABLE 4,
PLOT 1) / P, I 5, DM 0 / AUGUST 11, 1955, SA 30 /
LENINGRAD / ARCYES58OSD, (BELOSV59AFL)
NO.2 ID. DM 25,180
NO.3 ID. DM 25,90

DIAGRAM 27
NO.1 STAND OF SIBERIAN FIR (FOR DETAILS SEE TABLE 5,
PLOT 4) / P, I 3, DM 30,90 / SEPTEMBER 14, 1957, SA 34 /
TOMSK / BELOSV59AFL
NO.2 ID. DM 30,180
NO.3 ID. DM 0

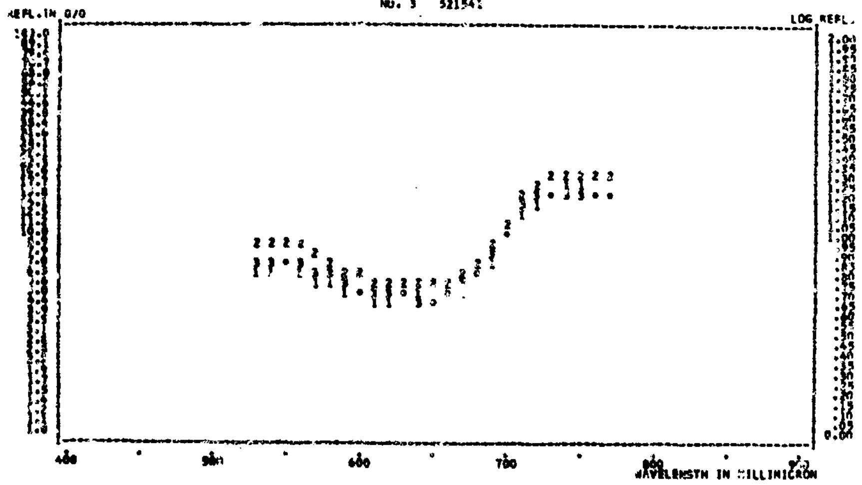
SPECTRAL REFLECTANCE CURVES

DIAGRAM 25



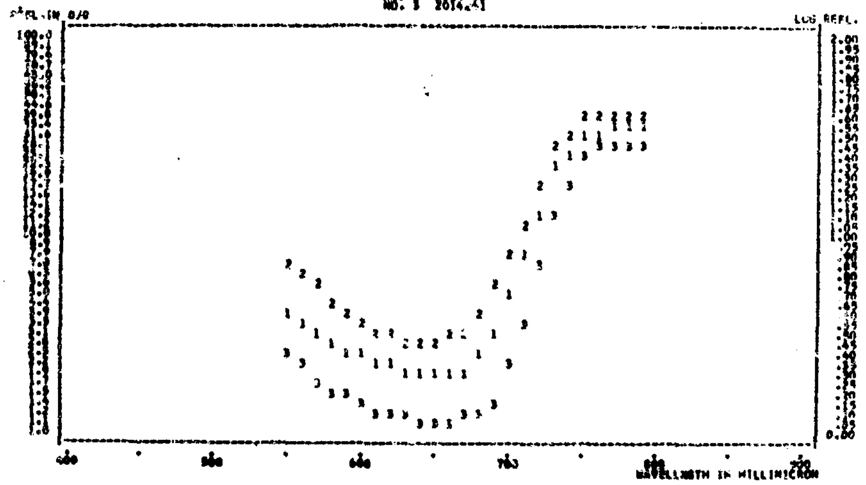
SPECTRAL REFLECTANCE CURVES

DIAGRAM 26



SPECTRAL REFLECTANCE CURVES

DIAGRAM 27



WAVE-LENGTH MMICR.	DIAGRAM 28 NO.1	NO.2	NO.3	DIAGRAM 29 NO.1	NO.2	NO.3	DIAGRAM 30 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	.	.	.	.	.	.	.	.	.
450	.	.	.	.	.	.	.	.	.
470	.	.	.	.	.	.	.	.	.
490	.	.	.	.	.	.	.	.	.
510	.	.	.	.	.	.	.	.	.
530	.	.	.	.	.	.	5.6	7.4	5.0
550	6.7	4.3	3.8	10.0	7.6	8.1	6.4	8.5	5.6
570	5.6	4.0	3.5	8.3	6.5	7.0	5.3	7.6	5.0
590	4.5	3.1	2.5	7.0	4.8	5.5	4.6	5.9	4.3
610	3.8	2.3	1.9	5.8	3.9	4.7	4.4	5.7	4.1
630	3.4	2.4	2.0	5.3	3.6	4.2	4.2	4.5	3.7
650	3.1	2.2	1.8	5.1	3.3	3.9	4.1	4.8	3.3
670	3.0	2.0	1.5	5.2	3.3	3.7	4.4	5.3	4.3
690	4.5	3.0	2.4	6.7	5.0	4.6	6.5	7.0	6.2
710	27.5	13.4	8.1	37.8	26.5	17.4	12.8	15.7	11.5
730	63.5	60.0	50.6	61.5	58.2	53.3	25.9	35.2	27.2
750	68.0	65.7	53.4	64.6	61.4	58.4	27.0	39.4	32.5
770	.	.	.	.	.	.	27.1	39.5	32.9
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

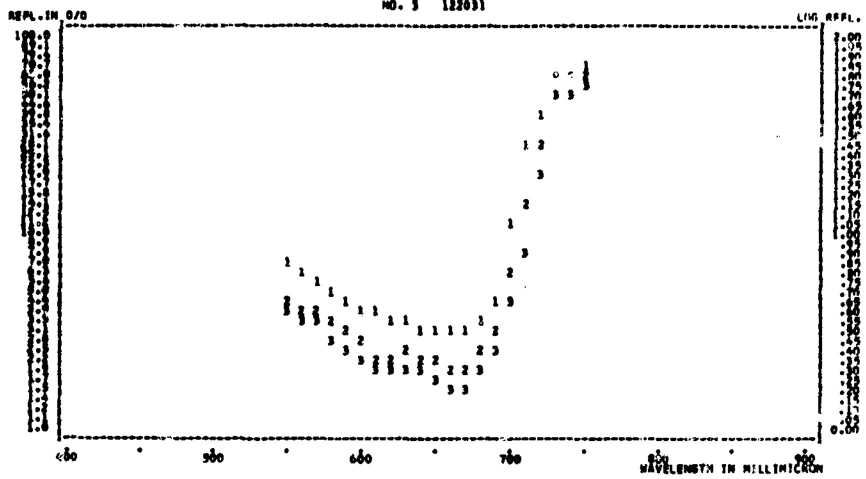
DIAGRAM 28
NO.1 STAND OF EUROPEAN WHITE BIRCH (FOR DETAILS SEE TABLE 6, PLOT 3) / P, I 3, DM 30,180 / JULY 11, 1958, SA 54 / L,VOV / ALEKVA60SDP
NO.2 ID. DM 0
NO.3 ID. DM 30,0

DIAGRAM 29
NO.1 STAND OF BEECH (FOR DETAILS SEE TABLE 6, PLOT 6) / P, I 3, DM 30,180 / JULY 11, 1958, SA 54 / L,VOV / ALEKVA60SDP
NO.2 ID. DM 0
NO.3 ID. DM 30,0

DIAGRAM 30
NO.1 STAND OF ASPEN MATURE (FOR DETAILS SEE TABLE 4, PLOT 4) P, I 5, DM 0 / AUGUST 11, 1955, SA 37 / LENINGRAD / KRCYES58OSD, (BELOSV59AFL)
NO.2 ID. DM 25,180
NO.3 ID. DM 25,90

SPECTRAL REFLECTANCE CURVES

DIAGRAM 28

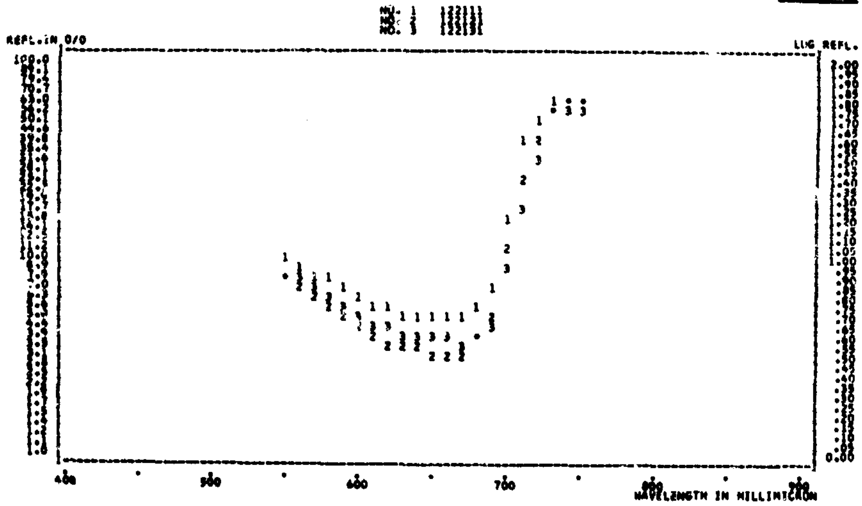


SPECTRAL REFLECTANCE CURVES

DIAGRAM 29

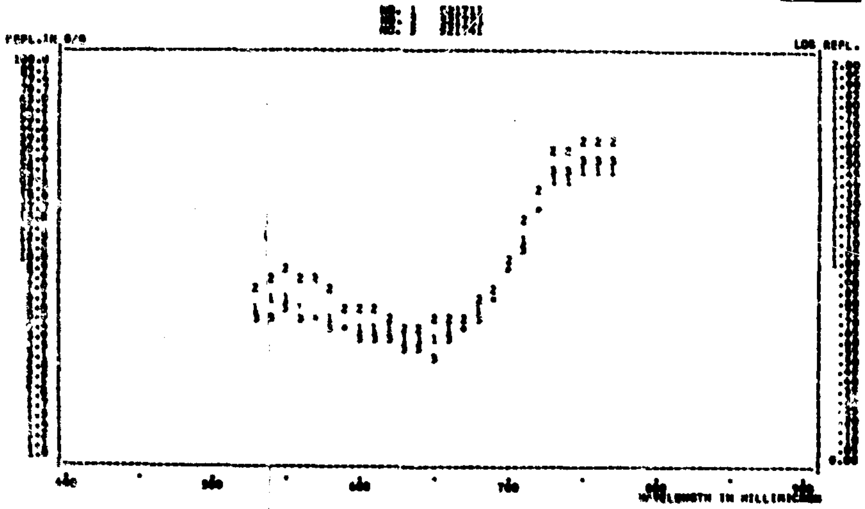
NO. 1 122111

NO. 3 122131



SPECTRAL REFLECTANCE CURVES

DIAGRAM 30



WAVE-LENGTH MMICR.	DIAGRAM 31 NO.1	NO.2	NO.3	DIAGRAM 32 NO.1	NO.2	NO.3	DIAGRAM 33 NO.1	NO.2	NO.3
400	21.2	7.5	4.5	.	.	.	70.0	30.5	15.0
430	21.0	7.2	5.2	.	.	.	71.3	29.0	15.5
450	22.0	7.4	5.7	6.8	6.1	6.5	74.0	29.0	16.0
470	23.2	7.8	6.5	7.0	6.2	6.6	76.0	29.7	15.4
490	24.2	9.0	7.3	7.4	6.8	7.1	78.0	30.8	15.2
510	24.5	10.0	7.0	8.0	7.2	7.5	79.8	32.2	16.0
530	25.0	11.5	8.7	9.1	7.8	8.2	81.0	33.0	17.3
550	24.9	14.0	9.6	10.8	8.5	9.0	82.0	32.6	16.8
570	25.5	14.8	9.3	12.9	9.0	9.3	83.0	32.0	16.6
590	27.0	15.7	9.5	14.7	9.5	9.7	84.0	32.1	17.5
610	28.0	17.0	10.1	16.1	10.1	9.3	85.5	33.5	18.2
630	28.0	19.4	11.5	17.5	10.5	9.0	87.5	33.6	18.6
650	27.8	20.4	12.1	18.6	11.3	8.7	88.1	33.6	18.3
670	27.6	20.8	12.2	20.0	12.[illegible]	9.0	88.2	33.6	18.0
690	27.4	21.4	12.3	23.3	14.2	10.7	88.2	33.4	17.5
710	.	.	.	27.9	16.3	14.3	.	.	.
730	.	.	.	31.2	18.0	16.0	.	.	.
750	.	.	.	34.5	19.8	16.8	.	.	.
770	.	.	.	37.5	21.5	17.4	.	.	.
790	.	.	.	4[illegible].0	23.1	18.0	.	.	.
810	.	.	.	42.5	24.8	18.6	.	.	.
830	.	.	.	44.5	26.1	19.2	.	.	.
850	.	.	.	46.2	27.7	19.9	.	.	.
870	.	.	.	47.5	28.7	20.7	.	.	.
890	.	.	.	48.2	29.5	21.4	.	.	.

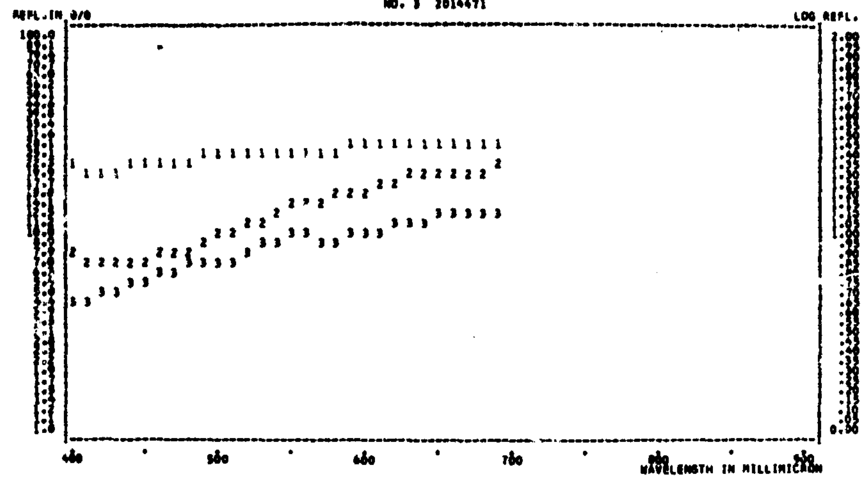
DIAGRAM 31
NO.1 BARK OF ASPEN (TREE * A 70) / G, I 1 / 1957, SA 20 / TOMSK / BELOSV59AFL
NO.2 PINE, BRANCHES FRESH, WITHOUT NEEDLES / G, I 1 / 1957, SA 34 / TOMSK / BELOSV59AFL
NO.3 ASPEN, BRANCHES FRESH, WITHOUT LEAVES / G, I 1 / 1957, SA 44 / TOMSK / BELOSR59AFL

DIAGRAM 32
NO.1 BARK OF SCOTCH PINE YOUNG, YELLOW-ORANGE / G, I 2,(1) OCTOBER 11, 1958, SA 31 / L,VOV / ALEKVA60SDP
NO.2 ID. OLD, BROWN
NO.3 BARK OF BEECH DARK GRAY / G, I 2,(1) / OCTOBER 11, 1958, SA 31 / L,VOV / ALEKVA60SDP

DIAGRAM 33
NO.1 BARK OF BIRCH WHITE, SMOOTH / G, I 1 / 1957, SA 20 / TOMSK / BELOSV59AFL
NO.2 ID. FROM LOWER PART OF STEM, WITH LONGITUDINAL DARK-GRAY FISSURES
NO.3 BARK OF SIBERIAN FIR FROM LOWER PART OF STEM, (TREE * A 70) / G, I 1 / 1957, SA 20 / TOMSK / BELOSV59AFL

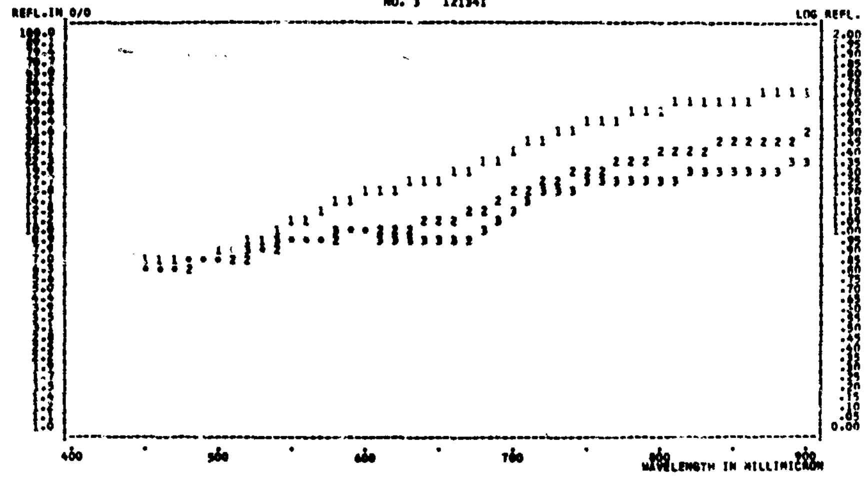
SPECTRAL REFLECTANCE CURVES

DIAGRAM 31



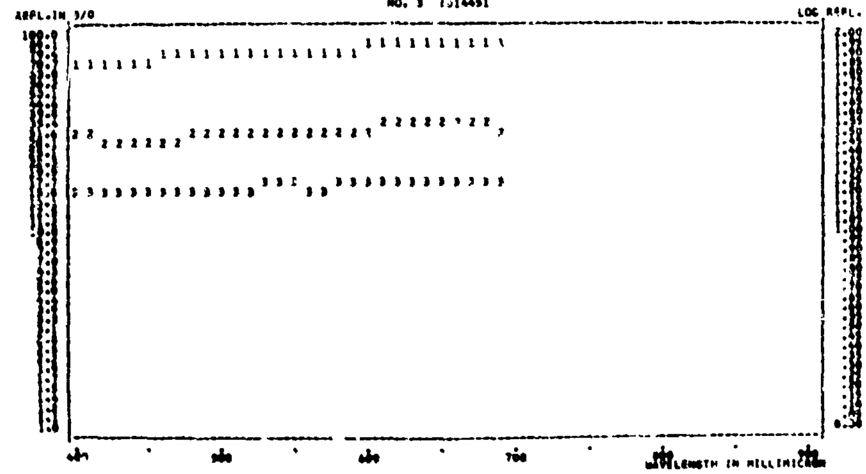
SPECTRAL REFLECTANCE CURVES

DIAGRAM 32



SPECTRAL REFLECTANCE CURVES

DIAGRAM 33



WAVE-LENGTH MMICR.	DIAGRAM 34 NO.1	NO.2	NO.3	DIAGRAM 35 NO.1	NO.2	NO.3	DIAGRAM 36 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	6.5	6.7	8.2	.	.	.	4.0	6.0	2.7
[illegible]	7.3	7.0	11.5	.	.	.	4.5	6.5	2.8
470	7.9	7.0	13.6	.	.	.	4.7	6.4	3.0
490	8.5	7.1	14.4	.	.	.	4.7	6.4	3.2
510	8.8	7.5	14.6	.	.	.	4.8	6.5	3.2
530	9.6	8.0	15.4	7.4	.	.	5.0	7.3	3.2
550	10.2	8.5	17.0	7.9	.	.	5.3	8.0	3.6
570	10.7	8.7	16.4	6.8	7.2	6.7	5.3	8.1	3.5
590	12.3	9.5	16.5	5.4	6.8	6.4	5.4	8.1	3.6
610	13.4	10.7	16.7	5.0	6.5	6.0	5.4	8.3	3.6
630	13.0	11.3	15.4	5.0	5.8	5.9	5.4	8.5	3.6
650	13.1	11.4	14.4	4.7	5.8	5.9	5.5	8.5	3.4
670	14.4	11.9	14.3	5.1	4.3	5.2	6.0	8.6	3.5
690	19.8	14.5	14.9	7.6	8.2	9.4	6.7	8.8	4.5
710	23.2	19.0	16.8	13.6	18.2	19.6	8.8	12.2	7.6
730	24.0	21.7	19.2	22.0	22.8	26.8	17.5	19.8	11.0
750	24.3	22.7	21.2	23.2	23.0	27.8	29.5	38.0	13.4
770	24.5	22.9	22.2	23.3	23.1	27.9	31.5	40.6	14.9
790	24.5	23.0	22.5	.	.	.	32.4	41.0	15.7
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

DIAGRAM 34

NO.1 NORWAY SPRUCE DRY BRANCHES WITHOUT NEEDLES, 60 PERCENT OF SURFACE COVERED WITH BEARD-MOSS / G, I 1,3 / AUGUST 10, 1957, SA 39 / TOMSK / BELOSV59AFL

NO.2 SIBERIAN STONE PINE DRY BRANCHES WITHOUT NEEDLES WITH 5 PERCENT BEARD-MOSS / G, I 1,3 / AUGUST 10, 1957, SA 39 / TOMSK / BELOSV59AFL

NO.3 BEARD-MOSS AIR-DRY / G, I 1,3 / AUGUST 10, 1957, SA 38 / TOMSK / BELOSV59AFL

DIAGRAM 35

NO.1 STAND OF BIRCH (FOR DETAILS SEE TABLE 4, PLOT 3) / P, I 5 / AUGUST 11, 1955, SA 36 TO 38 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)

NO.2 CLEARING WITH YOUNG GROWTH (50 PERCENT BIRCH, 40 PERCENT ASPEN, 10 PERCENT SPRUCE), H 1.3, B 0.6) / P, I 5 / AUGUST 9, 1955, SA 40 TO 41 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)

NO.3 ID. WITHOUT YOUNG GROWTH

DIAGRAM 36

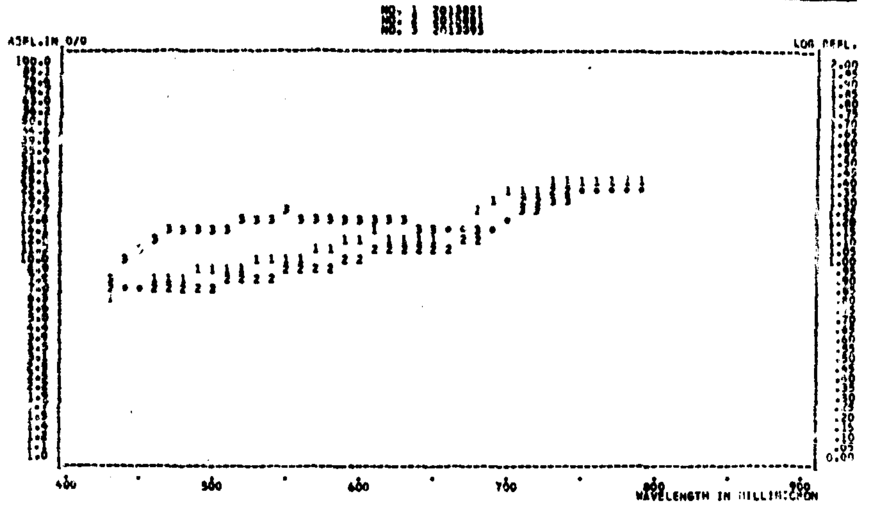
NO.1 STAND OF DEAD TREES (FOR DETAILS SEE TABLE 5, PLOT 5) / P, I 3, DM 30,90, AVERAGE OF 3 MEASUREMENTS / JULY TO AUGUST 1957, SA 48 / TOMSK / BELOSV59AFL

NO.2 ID. DM 30,180, 1 MEASUREMENT / SA 38

NO.3 ID. DM 30,0, AVERAGE OF 2 MEASUREMENTS / SA 48

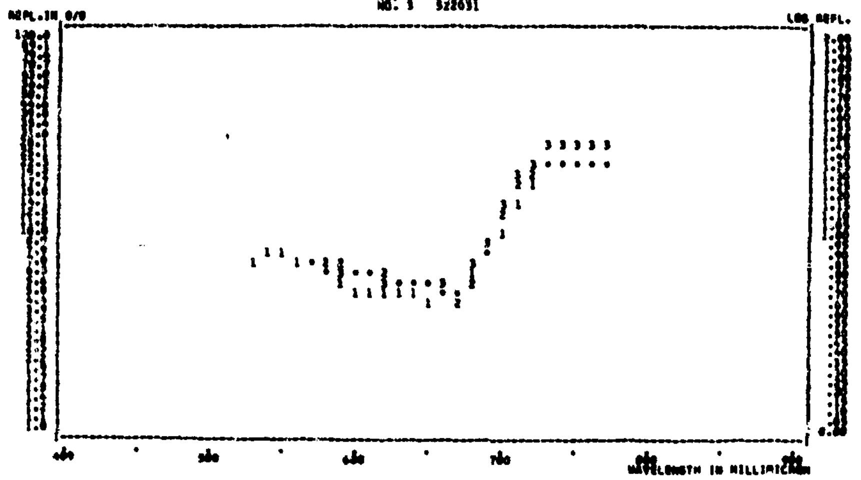
SPECTRAL REFLECTANCE CURVES

DIAGRAM 34



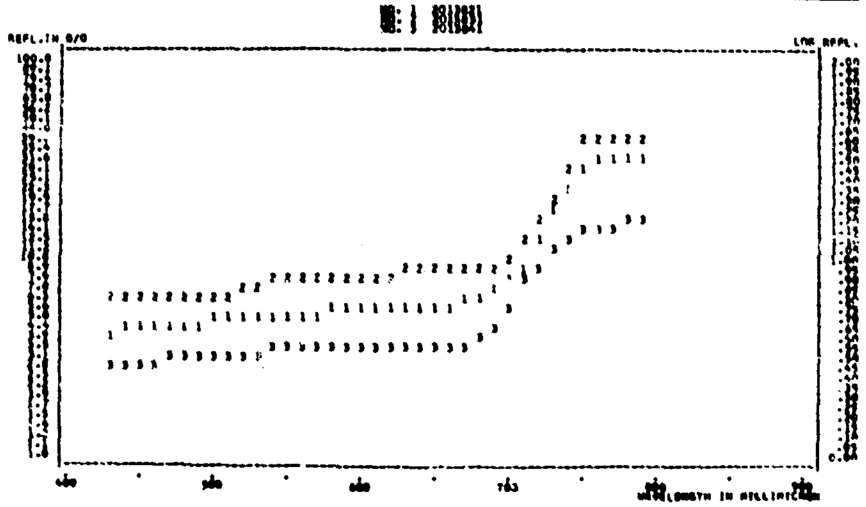
SPECTRAL REFLECTANCE CURVES

DIAGRAM 35



SPECTRAL REFLECTANCE CURVES

DIAGRAM 36

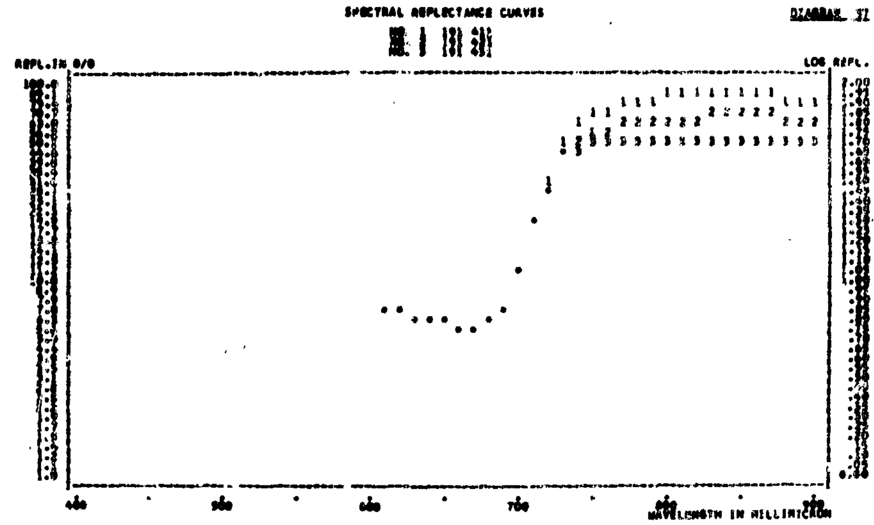


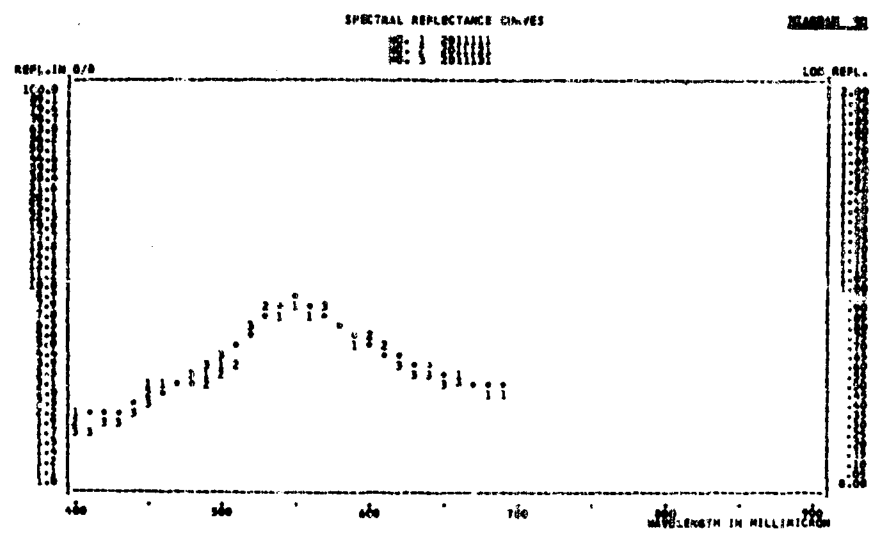
WAVE-LENGTH MMICR.	DIAGRAM 37			DIAGRAM 38			DIAGRAM 39		
	NO.1	NO.2	NO.3	NO.1	NO.2	NO.3	NO.1	NO.2	NO.3
400	.	.	.	2.3	2.1	1.7	.	.	.
430	.	.	.	2.3	2.2	2.1	.	.	.
450	.	.	.	3.0	2.7	2.4	5.2	3.3	6.0
470	.	.	.	3.1	3.0	3.1	4.5	3.7	6.5
490	.	.	.	3.5	3.3	4.0	4.5	4.0	7.5
510	.	.	.	4.8	4.2	5.2	6.8	5.5	8.5
530	.	.	.	6.8	7.5	7.1	8.7	7.3	10.0
550	.	.	.	8.0	8.6	8.6	9.4	8.5	11.5
570	.	.	.	6.7	7.4	7.5	8.7	8.1	12.5
590	.	.	.	5.3	5.9	5.7	7.6	7.7	13.5
610	7.0	7.0	7.0	4.7	4.9	4.7	7.2	7.7	14.0
630	6.5	6.5	6.5	4.2	4.1	3.7	6.5	7.3	14.6
650	6.0	6.0	6.0	3.7	3.5	3.3	4.9	6.5	15.4
670	5.5	5.5	5.5	3.1	3.2	3.2	3.3	5.7	15.8
690	7.0	7.0	7.0	2.8	3.0	3.1	5.4	8.4	16.4
710	19.5	19.5	19.5	.	.	.	9.2	17.1	17.1
730	51.5	45.0	43.0	.	.	.	29.5	21.7	17.8
750	70.5	56.0	49.0	.	.	.	44.1	25.0	18.6
770	79.0	62.0	52.0	.	.	.	48.2	26.9	19.3
790	83.0	64.5	53.0	.	.	.	49.1	28.0	20.0
810	86.0	66.0	53.0	.	.	.	49.0	28.6	20.5
830	86.0	67.0	52.8	.	.	.	48.8	29.0	20.8
850	85.0	67.0	52.5	.	.	.	48.3	29.5	21.2
870	84.5	67.0	52.3	.	.	.	47.8	29.5	21.7
890	83.5	66.5	52.0	.	.	.	47.3	29.5	22.3

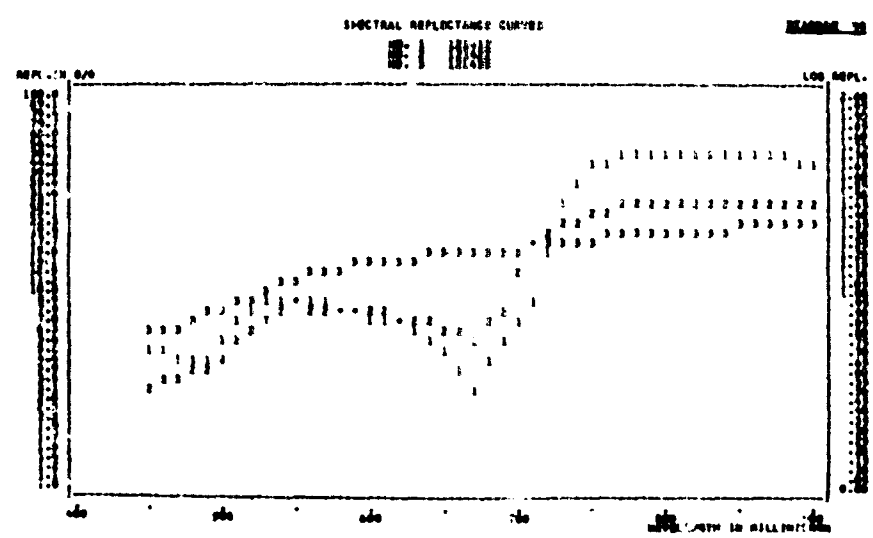
DIAGRAM 37
NO.1 EUROPEAN WHITE BIRCH ON WHITE PAPER (R = 0.9) / L, I 10 / ILINAA47JPO
NO.2 ID. ON GRAY PAPER (R = 0.35)
NO.3 ID. ON BLACK PAPER (R = 0.06)

DIAGRAM 38
NO.1 NORWAY SPRUCE 2 YEARS OLD SHOOTS / G, I 1 / SA 28 / BELOSV59AFL
NO.2 ID. SA 34
NO.3 ID. SA 40

DIAGRAM 39
NO.1 OATS WITH VETCH G, I 2,(1) / AUGUST 11, 1958, SA 53 / L,VOV / ALEKVA60SDP
NO.2 ID. STUBBLE-FIELD (SOIL VISIBLE THROUGH PLANTS)
NO.3 LOAMY SAND SOIL LIGHT-GRAY, WITH A BROWNISH TINT / G, I 2,(1) / AUGUST 11, 1958, SA 53 / L,VOV / ALEKVA60SDP


SPECTRAL REFLECTANCE CURVES
DIAGRAM 37
REFL.IN O/O
LOG REFL.
400
500
600
700
800
900
WAVELENGTH IN MILLIMICRON


SPECTRAL REFLECTANCE CURVES
REFL.IN O/O
LOG REFL.
400
500
600
700
800
900
WAVELENGTH IN MILLIMICRON


SPECTRAL REFLECTANCE CURVES
LOG REFL.
400
500
600
700
800
900

WAVE-LENGTH %MICR.	DIAGRAM 40 NO.1	DIAGRAM 40 NO.2	DIAGRAM 40 NO.3	DIAGRAM 41 NO.1	DIAGRAM 41 NO.2	DIAGRAM 41 NO.3	DIAGRAM 42 NO.1	DIAGRAM 42 NO.2	DIAGRAM 42 NO.3
400	3.0	5.0	.	5.4	2.1	.	.	.	.
430	2.4	5.5	.	4.9	3.4	.	5.7	2.7	.
450	2.4	5.7	.	4.8	3.5	.	7.0	3.8	.
470	2.5	5.9	.	4.7	4.0	.	8.2	4.0	.
490	2.4	6.2	.	4.8	4.0	.	9.0	5.0	.
510	2.8	7.6	.	5.7	5.2	.	11.3	6.3	.
530	3.4	9.8	.	7.7	7.7	.	14.5	7.0	.
550	3.7	11.0	.	9.0	9.4	.	17.0	8.0	.
570	3.4	10.8	.	8.9	9.1	.	15.5	7.7	.
590	2.9	9.6	.	8.3	8.3	.	14.0	7.3	.
610	2.9	9.5	.	8.4	8.0	.	12.8	6.0	.
630	2.6	10.0	.	7.7	8.2	.	12.0	5.8	.
650	2.6	9.1	.	7.4	7.6	.	10.0	5.3	.
670	.	.	.	.	.	.	9.3	5.2	.
690	.	.	.	.	.	.	.	.	.
710	.	.	.	.	.	.	.	.	.
730	.	.	.	.	.	.	.	.	.
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

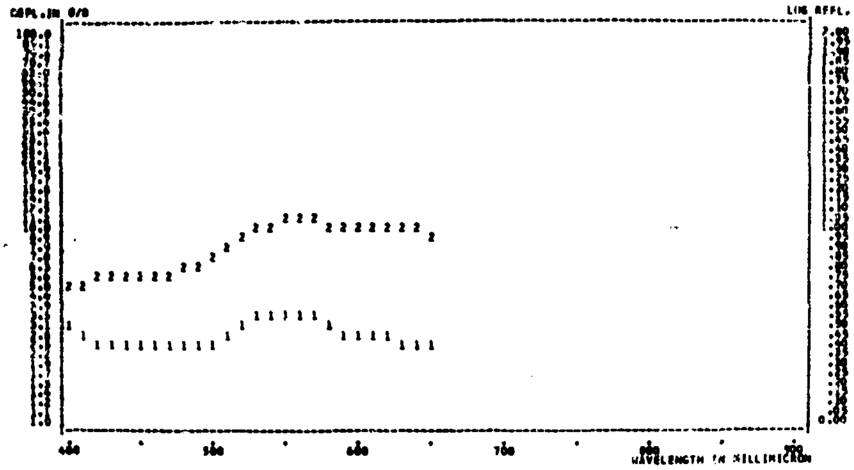
DIAGRAM 40
NO.1 STAND OF SPRUCE P (FLYING HEIGHT 300 M) / VINOAI55PAP, (KRINEL53SRP)
NO.2 ID. G, MEASURED HORIZONTALLY WITH THE SUN BEHIND THE OBSERVER

DIAGRAM 41
NO.1 MEADOW P (FLYING HEIGHT 300 M) / VINOAI55PAP, (KRINEL53SRP)
NO.2 ID. G

DIAGRAM 42
NO.1 BLACK SAXAUL BRANCHES / G, I 1 / (SUMMER) 1954 / SW TURKMENIA / LJALKS60IOP
NO.2 ID. WHOLE PLANT

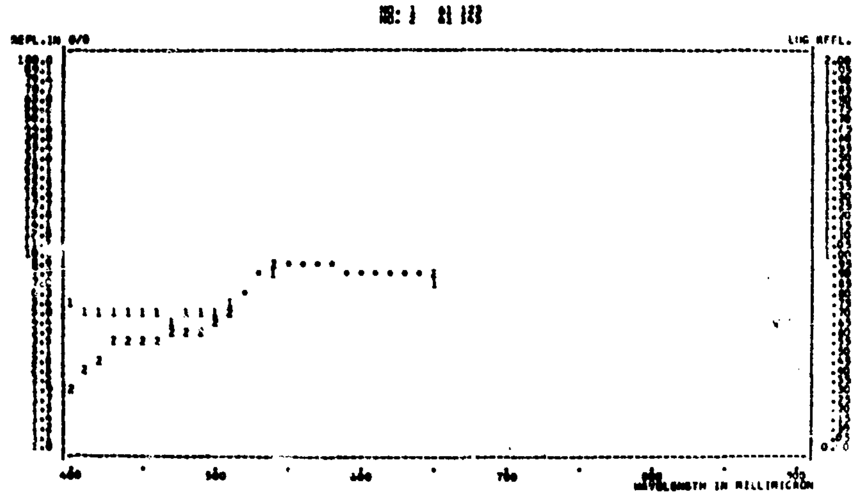
SPECTRAL REFLECTANCE CURVES

DIAGRAM 40



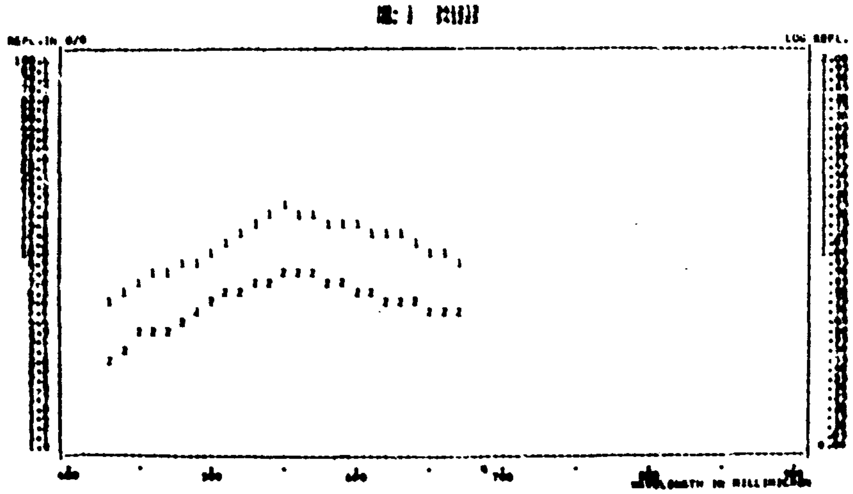
SPECTRAL REFLECTANCE CURVES

DIAGRAM 41



SPECTRAL REFLECTANCE CURVES

DIAGRAM 42



WAVE-LENGTH MMICR.	DIAGRAM 43 NO.1	DIAGRAM 43 NO.2	DIAGRAM 43 NO.3	DIAGRAM 44 NO.1	DIAGRAM 44 NO.2	DIAGRAM 44 NO.3	DIAGRAM 45 NO.1	DIAGRAM 45 NO.2	DIAGRAM 45 NO.3
400	.	.	.	1.9	2.0	3.1	.	.	.
430	1.3	1.8	2.2	1.9	2.3	3.3	1.3	2.0	1.8
450	1.7	2.1	2.5	2.1	2.4	3.5	1.5	2.4	2.2
470	2.5	2.3	2.8	2.1	2.4	3.5	1.6	2.9	2.7
490	3.0	2.9	3.6	2.1	2.4	3.6	2.1	3.7	3.2
510	3.5	4.5	4.3	2.5	3.1	4.5	2.8	4.8	3.7
530	4.4	5.0	4.1	4.0	4.7	5.8	3.3	5.8	4.3
550	4.4	5.5	4.4	4.8	5.3	6.4	3.7	6.3	5.1
570	3.8	5.1	[illegible]	4.3	4.9	5.9	3.3	5.6	4.4
590	2.6	4.5	4.0	3.5	4.6	5.2	3.0	4.6	3.6
610	2.2	4.2	3.8	3.0	4.1	4.6	3.0	3.6	3.0
630	2.2	3.8	3.6	2.9	3.7	4.0	3.0	.	2.8
650	2.4	3.5	3.8	2.8	3.5	3.8	2.5	.	2.9
670	3.0	3.3	4.7	2.7	3.3	4.2	1.8	.	3.3
690	4.5	4.0	5.4	9.6	5.0	7.0	2.7	.	5.6
710	7.1	7.0	10.5	29.0	25.8	20.7	7.5	.	22.8
730	16.7	14.3	24.5	40.0	42.0	51.0	14.5	.	46.2
750	23.0	19.7	36.0	44.0	46.2	61.2	17.3	.	50.0
770	24.0	21.7	37.0	44.6	47.1	62.7	17.5	.	50.8
790	24.0	22.2	37.2	44.6	47.[illegible]	52.9	17.6	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

DIAGRAM 43

NO.1 NORWAY SPRUCE WHOLE CROWN (STAND • A 160, S IV) / G, I 1,5 / JULY 3, 1956, SA 44 TO 47 / ARKHANGELSK / BELOSV59AFL

NO.2 SIBERIAN LARCH WHOLE CROWN (STAND • A 160, S III TO IV) G, I 1,5 / AUGUST 20, 1956, SA 36 TO 38 / ARKHANGELSK / BELOSV59AFL

NO.3 ASPEN WHOLE CROWN (STAND • A 30, S III) / G, I 1,5 / AUGUST 20, 1956, SA 38 / ARKHANGELSK / BELOSV59AFL

DIAGRAM 44

NO.1 SIBERIAN FIR WHOLE CROWN (STAND • A 70 TO 120, S II, B 0.8) / G, I 1,3, AVERAGE OF 4 TREES / AUGUST 7 TO 10, 1957, SA 3[illegible] / TOMSK / BELOSV59AFL

NO.2 SIBERIAN STONE PINE WHOLE CROWN (STAND • A 120, S II, B 0.8) / G, I 1,3, AVERAGE OF 2 TREES / AUGUST 3 TO 7, 1957, SA 45 / TOMSK / BELOSV59AFL

NO.3 ASPEN WHOLE CROWN (STAND • A 45, S II, B 0.8) / G, I 1,3 / AUGUST 12, 1957, SA 34 / TOMSK / BELOSV59AFL

DIAGRAM 45

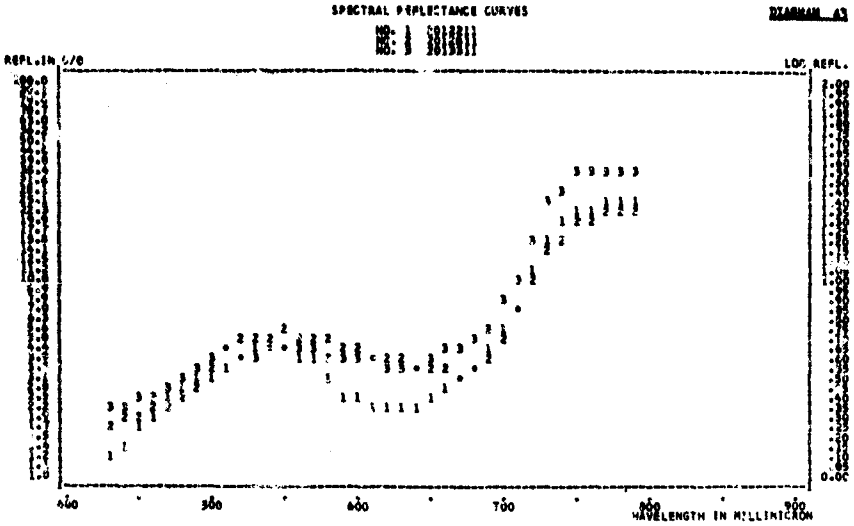
NO.1 NORWAY SPRUCE WHOLE CROWN (STAND • A 170, S IV) / G, I 1,5 / JULY 7, 1956, SA 44 TO 46 / ARKHANGELSK / BELOSV59AFL

NO.2 SCOTCH PINE WHOLE CROWN (STAND • A 140, S IV) / G, I 1,5 / AUGUST [illegible], 1956, SA 41 / ARKHANGELSK / BELOSV59AFL

NO.3 BIRCH WHOLE CROWN (STAND • A 80, S IV / G, I 1,5 JULY 6, 1956, SA 45 TO 46 / ARKHANGELSK / BELOSV59AFL

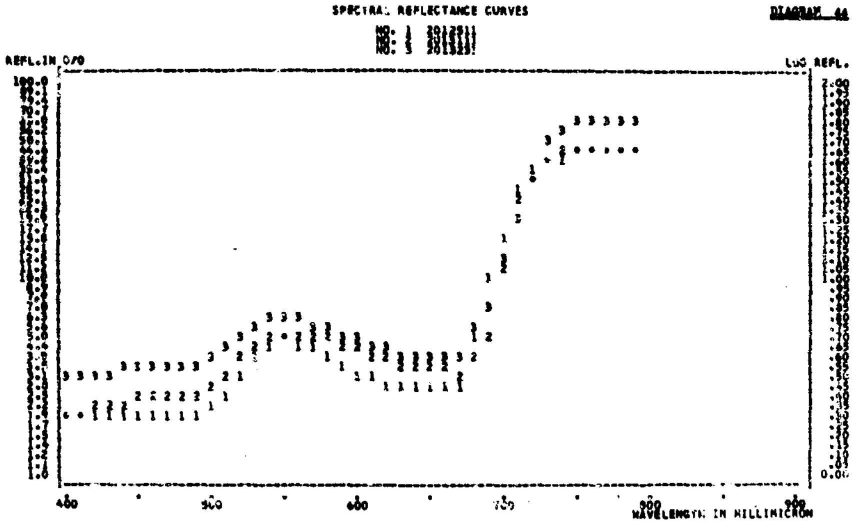
SPECTRAL REFLECTANCE CURVES

DIAGRAM 43



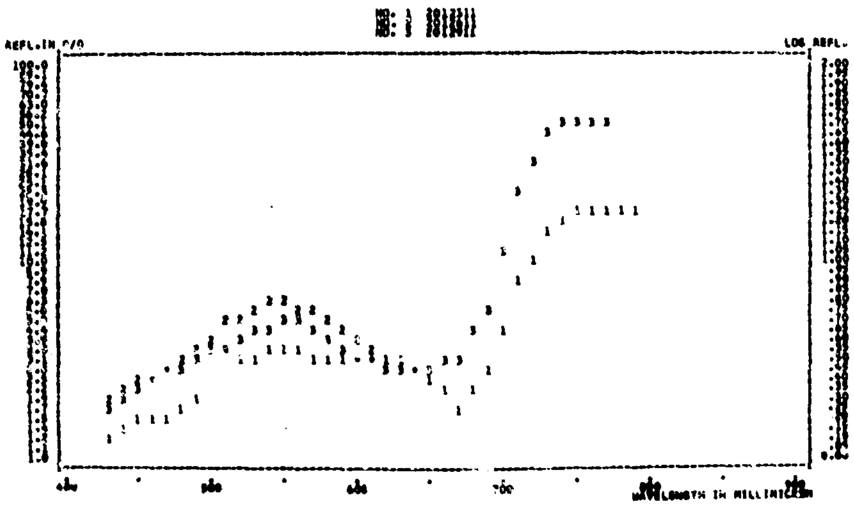
SPECTRAL REFLECTANCE CURVES

DIAGRAM 44



SPECTRAL REFLECTANCE CURVES

DIAGRAM 45



WAVE-LENGTH MMICR.	DIAGRAM 46 NO.1	NO.2	NO.3	DIAGRAM 47 NO.1	NO.2	NO.3	DIAGRAM 48 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	.	.	.	.	.	.	.	.	.
450	3.5	5.8	4.0	2.5	4.3	3.2	3.0	[illegible]	.
470	3.0	5.9	2.6	2.4	4.3	2.7	2.7	9.2	.
490	3.2	6.3	2.4	2.5	4.7	2.7	2.7	9.8	.
510	3.8	7.8	4.0	3.5	5.5	3.7	3.2	13.8	3.2
530	4.9	10.5	7.3	5.0	8.5	7.5	4.6	23.8	3.6
550	6.0	12.5	9.2	5.6	9.9	9.3	5.6	32.6	4.5
570	5.6	10.0	8.0	4.8	8.5	7.8	5.0	40.0	5.8
590	4.4	8.4	6.8	4.5	7.3	6.0	3.8	42.3	7.7
610	4.4	8.6	5.8	4.5	7.1	4.9	3.3	42.0	8.7
630	4.4	8.4	5.4	4.3	6.4	4.2	3.3	43.5	9.4
650	4.2	7.2	4.6	4.1	5.7	3.1	3.2	43.5	9.8
670	4.4	7.5	4.4	3.5	6.4	3.6	3.0	43.2	10.7
690	7.0	14.3	9.8	6.6	9.5	8.3	3.7	46.0	12.5
710	14.4	36.8	39.5	16.1	30.5	24.0	9.0	49.8	15.5
730	22.4	57.0	65.2	23.0	52.0	52.5	15.8	52.1	17.9
750	25.8	61.3	69.5	26.1	57.0	60.0	18.9	53.2	18.1
770	25.0	63.2	71.1	26.6	58.0	60.4	19.2	54.2	18.5
790	25.7	64.2	72.6	27.2	58.1	61.0	19.7	55.6	19.8
810	25.8	65.2	73.3	27.4	58.8	61.5	20.1	56.8	21.3
830	26.1	66.5	73.9	27.5	59.6	62.0	20.6	57.8	23.0
850	26.3	67.5	73.8	27.7	60.0	62.2	21.1	58.3	24.3
870	26.6	68.1	74.0	28.0	60.3	62.8	21.3	58.7	25.3
890	26.7	67.5	74.1	28.1	60.4	63.0	21.4	58.7	25.8

DIAGRAM 46

NO.1 SCOTCH PINE 1 TO 2 YEARS OLD SHOOTS (DETAILS AS FOR DIAG. 1) / G, I 2,(1) / AUGUST 1, 1958, SA 57 / L,VOV / ALEKVA60SDP

NO.2 EUROPEAN WHITE BIRCH GREEN LEAVES (DETAILS AS FOR DIAG. 18) / G, I 2,(1) / JULY 31, 1958, SA 51 / L,VOV / ALEKVA60SDP

NO.3 BEECH GREEN LEAVES (DETAILS AS FOR DIAG. 16) / G, I 2,(1) / JULY 31, 1958, SA 58 / L,VOV / ALEKVA60SDP

DIAGRAM 47

NO.1 NORWAY SPRUCE 1 TO 2 YEARS OLD SHOOTS (DETAILS AS FOR DIAG. 4) / G, I 2,(1) / JULY 31, 1958, SA 49 / L,VOV / ALEKVA60SDP

NO.2 ASPEN GREEN LEAVES / G, I 2,(1) / AUGUST 1, 1958, SA 43 / L,VOV / ALEKVA60SDP

NO.3 ASH GREEN LEAVES / G, I 2,(1) / AUGUST 1, 1958, SA 52 / L,VOV / ALEKVA60SDP

DIAGRAM 48

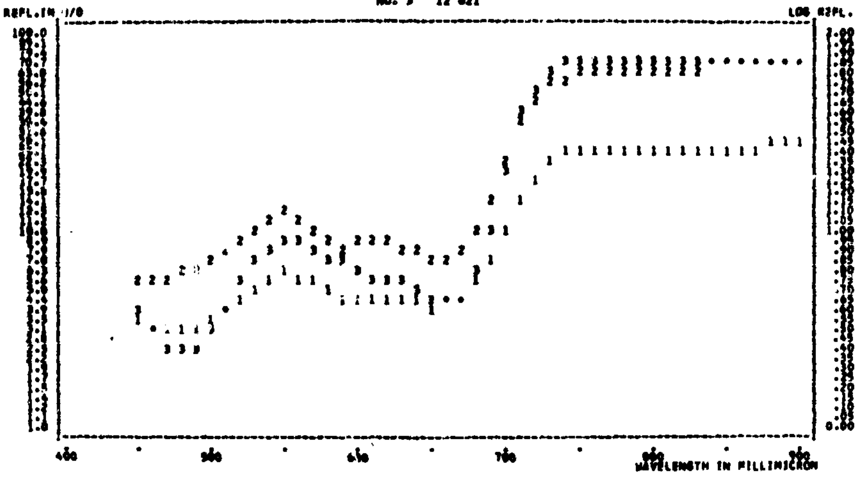
NO.1 SCOTCH PINE 1 TO 2 YEARS OLD SHOOTS (DETAILS AS FOR DIAG. 1) / G, I 2,(1) / / OCTOBER 12, 1958, SA 31 / L,VOV / ALEKVA60SDP

NO.2 EUROPEAN WHITE BIRCH YELLOW LEAVES (DETAILS AS FOR DIAG. 18) / G, I 2,(1) / OCTOBER 11, 1958, SA 34 / L,VOV ALEKVA60SDP

NO.3 BEECH DRY LEAVES, GRAYISH-BROWN (DETAILS AS FOR DIAG. 16) / G, I 2,(1) / OCTOBER 10, 1958, SA 32 / L,VOV / ALEKVA60SDP

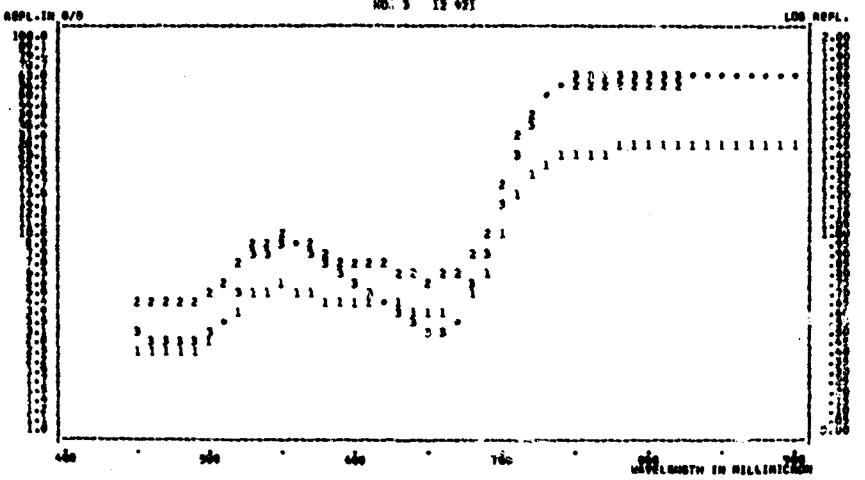
SPECTRAL REFLECTANCE CURVES

DIAGRAM 46



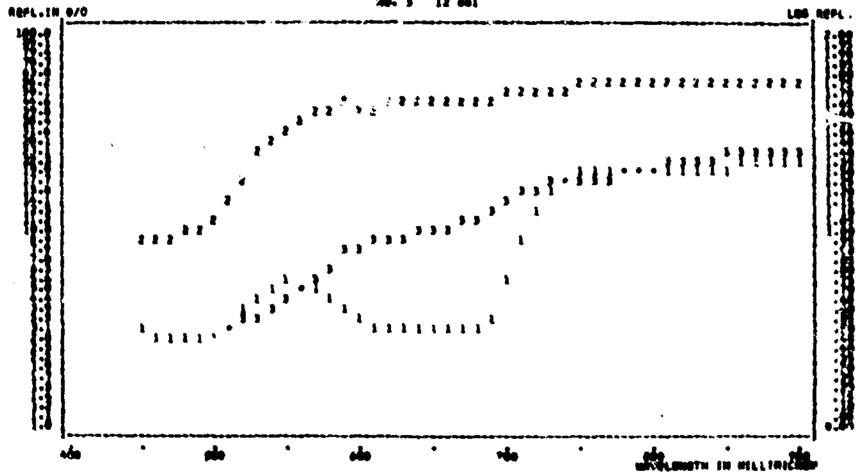
SPECTRAL REFLECTANCE CURVES

DIAGRAM 47



SPECTRAL REFLECTANCE CURVES

DIAGRAM 48



WAVE-LENGTH MMICR.	DIAGRAM 49 NO.1	NO.2	NO.3	DIAGRAM 50 NO.1	NO.2	NO.3	DIAGRAM 51 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	.	.	.	.	.	.	.	.	.
450	1.6	5.5	5.5	8.3	7.5	5.8	5.8	4.0	3.2
470	1.3	5.5	5.5	8.8	7.4	6.1	5.9	2.6	2.7
490	.8	5.9	6.0	9.6	7.7	7.0	6.3	2.4	2.7
510	1.6	9.3	9.7	11.5	8.5	10.9	7.8	4.0	3.7
530	3.0	18.4	18.6	15.4	10.7	16.0	10.5	7.3	7.5
550	3.8	24.6	23.1	17.5	11.4	18.2	12.5	9.2	9.3
570	3.1	28.5	20.5	15.5	10.7	16.0	10.0	8.0	7.8
590	2.6	30.5	17.2	14.0	9.5	13.7	8.4	6.8	6.0
610	2.1	31.7	16.0	13.5	8.3	11.2	8.6	5.8	4.9
630	2.0	31.3	14.1	12.4	7.4	9.6	8.4	5.4	4.2
650	2.1	29.8	9.7	10.9	6.0	8.6	7.2	4.6	3.1
670	2.4	28.0	7.7	11.8	5.6	8.5	7.5	4.4	3.6
690	4.4	29.0	10.5	21.5	9.4	10.4	14.3	9.8	8.3
710	10.6	41.0	39.5	53.5	29.8	30.4	36.8	39.5	24.0
730	18.2	43.8	49.0	73.2	62.5	64.9	57.0	65.2	52.5
750	20.8	45.5	53.3	78.2	74.0	77.4	61.3	69.5	60.0
770	21.2	46.7	54.2	79.8	75.7	78.0	63.2	71.1	60.4
790	21.5	47.9	54.8	80.2	75.5	78.0	64.2	72.6	61.0
810	22.6	48.6	55.5	80.2	75.5	78.0	65.2	73.3	61.5
830	22.8	49.7	56.2	80.3	75.5	78.0	66.5	73.9	62.0
850	22.9	50.7	56.8	80.3	75.6	78.0	67.5	73.8	62.2
870	23.5	51.7	57.0	80.4	75.7	78.0	68.1	74.0	62.8
890	23.3	52.6	57.0	80.4	75.9	78.0	67.5	74.1	63.0

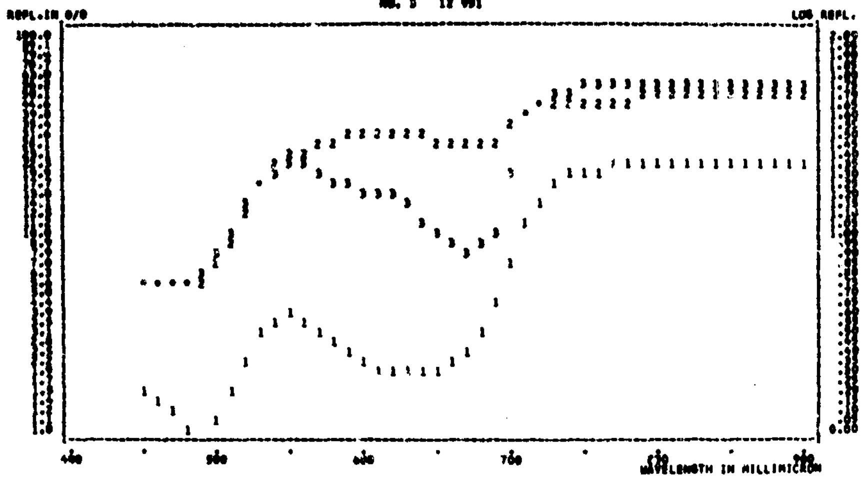
DIAGRAM 49
NO.1 NORWAY SPRUCE 1 TO 2 YEARS OLD SHOOTS (DETAILS AS FOR DIAG. 4) / G, I 2,(1) / SEPTEMBER 29, 1958, SA 30 / L,VOV / ALEKVA60SDP
NO.2 ASPEN YELLOW LEAVES / G, I 2,(1) / OCTOBER 11, 1958, SA 32 / L,VOV / ALEKVA60SDP
NO.3 ASH YELLOW LEAVES / G, I 2,(1) / OCTOBER 12, 1958, SA 29 / L,VOV / ALEKVA60SDP

DIAGRAM 50
NO.1 EUROPEAN WHITE BIRCH GREEN LEAVES (DETAILS AS FOR DIAG. 18) / G, I 2,(1) / JUNE 17, 1958, SA 43 / L,VOV / ALEKVA60SDP
NO.2 ASH GREEN LEAVES / G, I 2,(1) / JUNE 7, 1958. SA 60 / L,VOV / ALEKVA60SDP
NO.3 ENGLISH OAK GREEN LEAVES / G, I 2,(1) / JUNE 8, 1958, SA 60 / L,VOV / ALEKVA60SDP

DIAGRAM 51
NO.1 EUROPEAN WHITE BIRCH GREEN LEAVES (DETAILS AS FOR DIAG. 18) / G, I 2,(1) / JULY 31, 1958, SA 51 / L,VOV / ALEKVA60SDP
NO.2 BEECH GREEN LEAVES (DETAILS AS FOR DIAG. 16) / G, I 2,(1) / JULY 31, 1958, SA 58 / L,VOV / ALEKVA60SDP
NO.3 ASH GREEN LEAVES / G, I 2,(1) / AUGUST 1, 1958, SA 52 / L,VOV / ALEKVA60SDP

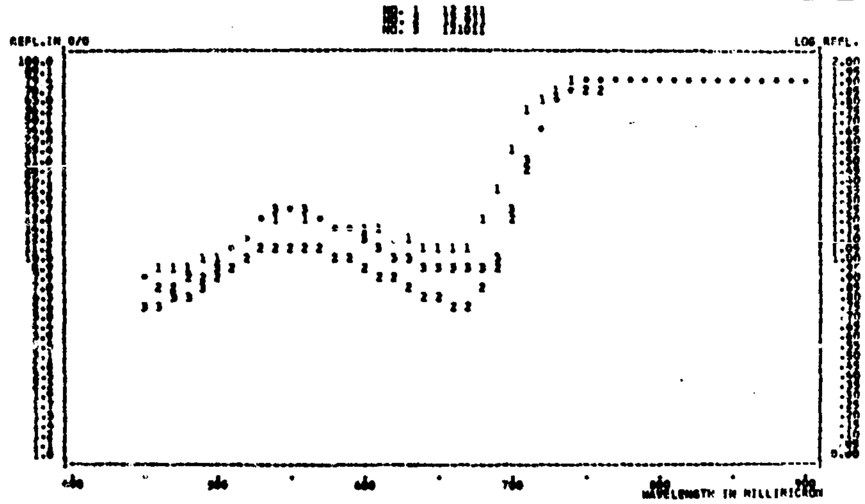
SPECTRAL REFLECTANCE CURVES

DIAGRAM 49



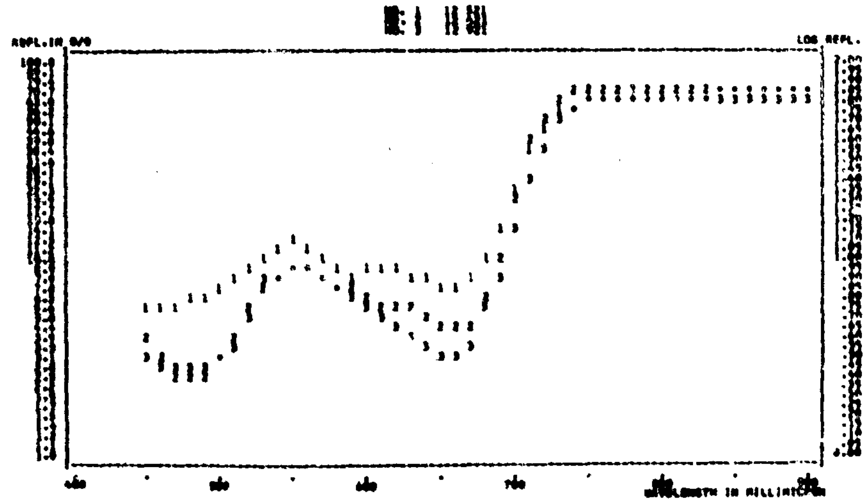
SPECTRAL REFLECTANCE CURVES

DIAGRAM 50



SPECTRAL REFLECTANCE CURVES

DIAGRAM 51



WAVE-LENGTH MMICR.	DIAGRAM 52 NO.1	NO.2	NO.3	DIAGRAM 53 NO.1	NO.2	NO.3	DIAGRAM 54 NO.1	NO.2	NO.3
400	.	.	.	1.8	2.0	2.8	.	.	.
430	.	.	.	2.0	2.0	3.0	.	.	.
450	2.5	6.5	3.0	2.1	2.3	3.1	.	.	.
470	2.8	6.6	3.1	2.3	2.5	3.2	.	.	.
490	3.2	6.8	3.5	2.5	3.0	3.3	.	.	.
510	3.9	7.2	3.9	3.0	3.6	4.1	6.4	30.0	14.3
530	4.5	7.6	4.5	3.8	4.7	5.3	9.5	32.3	18.5
550	5.5	8.0	5.0	5.5	6.0	6.0	11.8	33.8	22.0
570	6.7	8.6	5.5	4.8	5.7	5.5	13.0	35.0	25.5
590	8.0	9.4	5.9	3.7	5.0	4.7	13.2	34.7	27.0
610	9.1	10.0	6.2	3.3	4.6	4.0	13.3	36.8	27.4
630	9.6	10.2	6.5	3.2	4.3	3.6	13.5	36.7	27.8
650	10.2	10.6	6.9	2.8	4.0	3.8	14.5	36.3	28.3
670	11.2	11.1	7.8	2.5	4.5	4.3	13.0	37.0	28.2
690	13.5	11.7	8.5	5.5	7.5	13.5	13.9	37.3	28.9
710	16.2	12.5	8.9	17.4	25.0	29.0	24.2	41.3	30.7
730	18.0	13.1	9.2	34.3	40.5	49.0	32.7	45.7	32.0
750	18.8	13.9	9.6	44.2	46.7	59.0	36.2	48.0	32.9
770	19.4	14.9	10.0	45.0	47.7	60.8	38.4	48.5	34.0
790	20.5	15.8	10.4	45.0	48.0	60.9	39.5	49.2	36.0
810	21.7	16.6	10.8	.	.	.	40.0	49.8	37.5
830	23.0	17.4	11.1	.	.	.	41.0	50.5	38.5
850	24.5	18.4	11.9	.	.	.	.	.	.
870	25.2	19.4	12.5	.	.	.	.	.	.
890	25.8	20.6	13.1	.	.	.	.	.	.

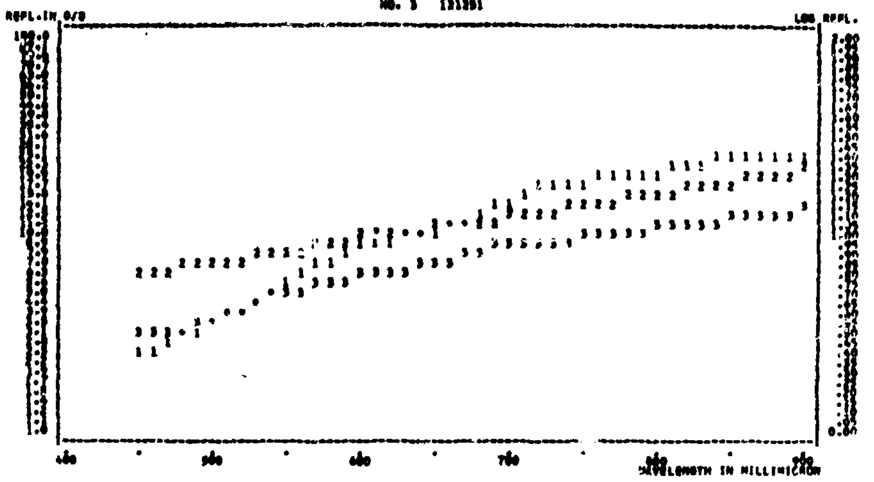
DIAGRAM 52
NO.1 BEECH DRY LEAVES, GRAYISH-BROWN / G, I 2,(1) / OCTOBER 11, 1958, SA 31 / L.VOV / ALEKVA60SDP
NO.2 ASPEN DRY LEAVES, GRAY / G, I 2,(1) / OCTOBER 11, 1958, SA 31 / L,VOV / ALEKVA60SDP
NO.3 SCOTCH PINE DRY NEEDLES, GRAY / G, I 2,(1) / OCTOBER 11, 1958, SA 31 / L,VOV / ALEKVA60SDP

DIAGRAM 53
NO.1 SIBERIAN SPRUCE WHOLE CROWN (STAND * A 70, S II, B 0.8) G, I 1,3, AVERAGE OF 2 TREES / AUGUST 4 TO 11, 1957, SA 40 / TOMSK / BELOSV59AFL
NO.2 SCOTCH PINE WHOLE CROWN (STAND * A 40, S II, B 0.5) / G, I 1,3, AVERAGE OF 2 TREES / AUGUST 3 TO 7, 1957, SA 46 / TOMSK / BELOSV59AFL
NO.3 BIRCH WHOLE CROWN (STAND * A 45, S II, B 0.8) / G, I 1,3 / AUGUST 7, 1957, SA 31 / TOMSK / BELOSV59AFL

DIAGRAM 54
NO.1 MOSS BROWN / I 6 / WESTERN YAKUTIA / BAKHVM50MSA (AFTER Z.L. PETRUSHKINA)
NO.2 REINDEER MOSS I 6 / WESTERN YAKUTIA / BAKHVM60MSA (AFTER Z.L. PETRUSHKINA)
NO.3 LIMESTONE COVERED WITH LICHENS / I 6 / WESTERN YAKUTIA / BAKHVM60MSA (AFTER Z.L. PETRUSHKINA)

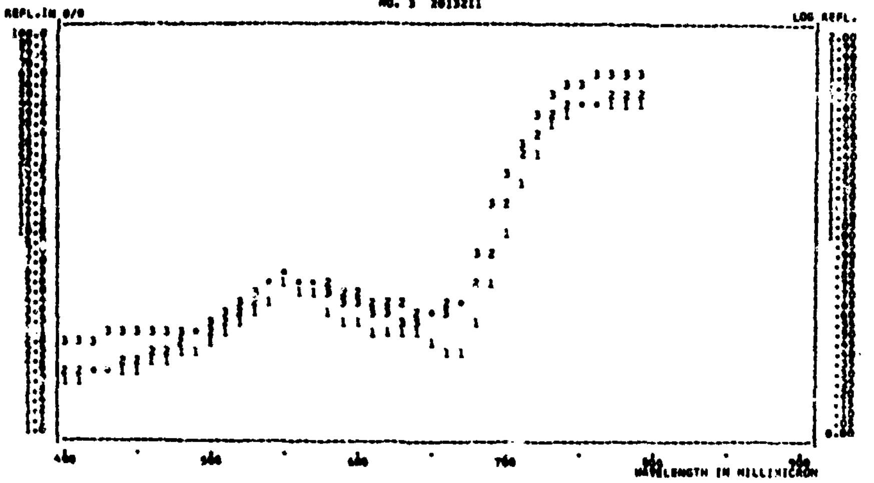
SPECTRAL REFLECTANCE CURVES

DIAGRAM 52



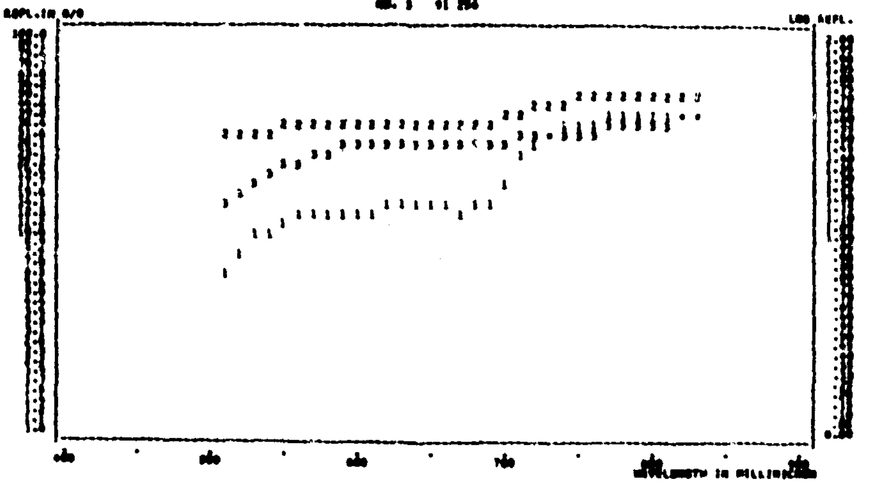
SPECTRAL REFLECTANCE CURVES

DIAGRAM 53



SPECTRAL REFLECTANCE CURVES

DIAGRAM 54



WAVE-LENGTH MMICR.	DIAGRAM 55 NO.1	NO.2	NO.3	DIAGRAM 56 NO.1	NO.2	NO.3	DIAGRAM 57 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	.	.	.	.	.	.	.	.	.
450	.	.	.	1.2	2.0	2.5	4.7	2.7	2.3
470	.	.	.	1.2	2.0	2.6	5.3	3.3	2.3
490	.	.	.	1.2	2.1	3.0	6.3	4.3	2.7
510	.	.	.	1.7	2.6	4.1	10.3	6.8	3.9
530	.	.	.	2.5	3.5	5.3	16.2	14.2	5.3
550	4.3	7.6	7.4	3.0	4.1	5.7	21.2	17.0	5.9
570	4.0	6.5	6.3	2.7	3.8	5.0	24.8	19.3	5.8
590	3.1	4.8	5.0	2.1	3.1	4.0	26.4	22.4	4.8
610	2.3	3.9	4.3	1.9	2.5	3.1	27.2	24.4	4.1
630	2.4	3.6	3.7	1.8	2.2	2.6	27.8	25.4	3.8
650	2.2	3.3	3.5	1.8	2.3	2.6	28.1	25.8	3.5
670	2.0	3.3	3.4	1.8	2.6	3.0	28.3	25.5	3.5
690	3.0	5.0	3.8	2.1	3.1	3.4	28.3	25.0	3.5
710	13.4	26.5	22.8	.	.	.	.	.	.
730	60.0	58.2	55.1	.	.	.	.	.	.
750	65.7	61.4	60.1	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

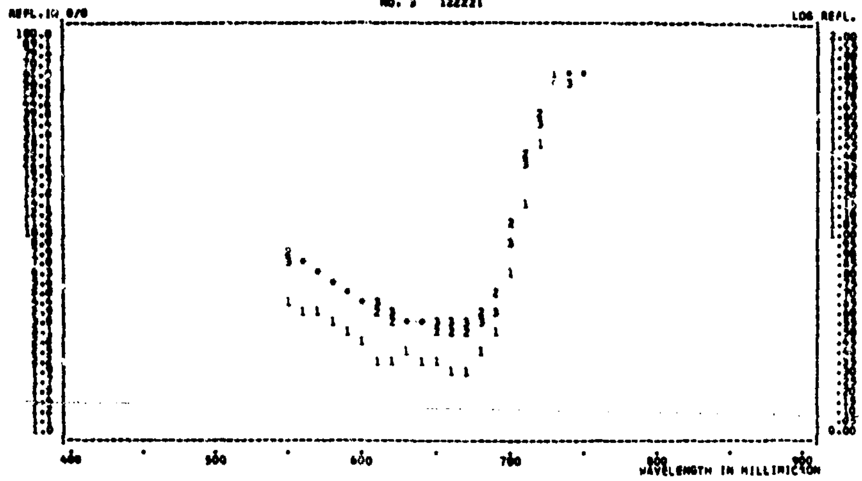
DIAGRAM 55
NO.1 STAND OF EUROPEAN WHITE BIRCH (FOR DETAILS SEE TABLE 6, PLOT 3) / P, I 3, DM 0 / JULY 11, 1958, SA 54 / L,VOV / ALEKVA60SDP
NO.2 STAND OF BEECH (FOR DETAILS SEE TABLE 6, PLOT 6) / P, I 3, DM 0 / JULY 11, 1958, SA 54 / L,VOV / ALEKVA60SDP
NO.3 STAND OF EUROPEAN ALDER (FOR DETAILS SEE TABLE 6, PLOT 7) / P, I 3, DM 0 / JULY 11, 1958, SA 54 / L,VOV / ALEKVA60SDP

DIAGRAM 56
NO.1 SCOTCH PINE G, I 1 / SEPTEMBER 9, 1955 /LENINGRAD / ARCYES58OSD
NO.2 BIRCH G, I 1 / SEPTEMBER 9, 1955 / LENINGRAD / ARCYES58OSD
NO.3 ASPEN G, I 1 / SEPTEMBER 9, 1955 / LENINGRAD / ARCYES58OSD

DIAGRAM 57
NO.1 BIRCH LEAVES WITH FALL COLORATION / G, I 1 / OCTOBER 8, 1955 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)
NO.2 ASPEN LEAVES WITH FALL COLORATION / G, I 1 / OCTOBER 8, 1955 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)
NO.3 SCOTCH PINE G, I 1 / OCTOBER 8, 1955 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)

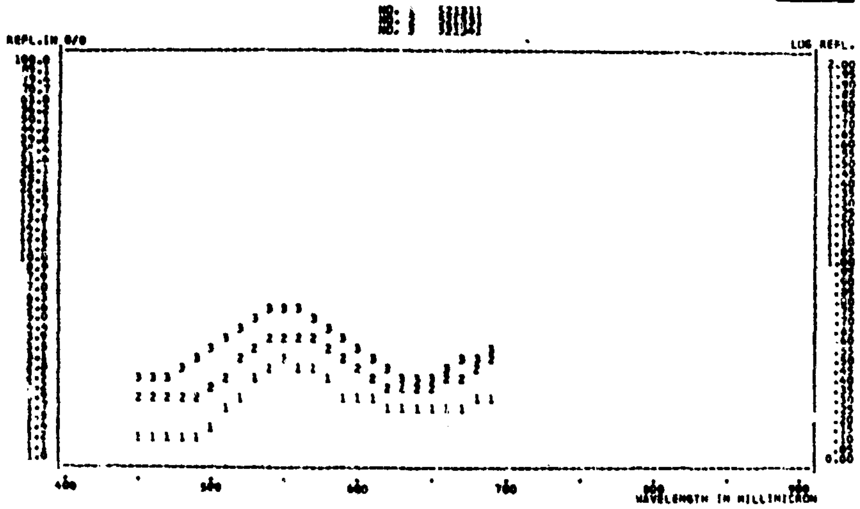
SPECTRAL REFLECTANCE CURVES

DIAGRAM 55



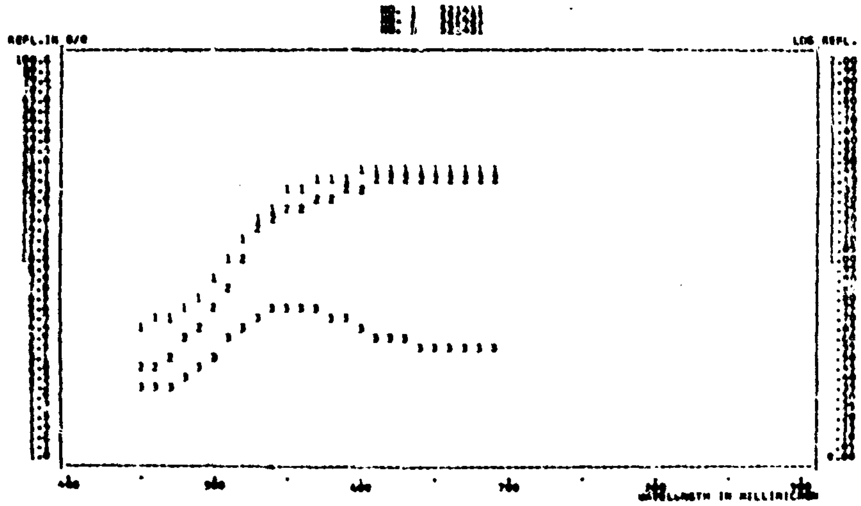
SPECTRAL REFLECTANCE CURVES

DIAGRAM 56



SPECTRAL REFLECTANCE CURVES

DIAGRAM 57



WAVE-LENGTH MMICR.	DIAGRAM 58 NO.1	NO.2	NO.3	DIAGRAM 59 NO.1	NO.2	NO.3	DIAGRAM 60 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	.	.	.	.	.	.	.	.	.
450	2.4	1.9	1.0	1.7	1.4	.9	.	.	.
470	2.0	2.0	1.3	2.0	1.4	1.7	.	.	.
490	2.0	2.1	1.2	1.6	1.4	1.1	.	.	.
510	2.6	2.8	1.3	2.8	2.0	1.4	.	.	.
530	4.2	4.3	1.6	3.2	3.1	2.1	6.4	7.4	5.6
550	4.6	4.7	2.2	3.0	3.4	2.4	7.0	7.9	6.0
570	3.6	3.7	2.0	2.8	2.3	2.0	6.0	6.8	5.1
590	3.1	3.1	1.4	2.0	2.0	1.7	5.0	5.4	4.4
610	2.8	2.7	1.5	2.1	2.1	1.9	4.7	5.0	4.2
630	2.3	2.2	1.4	2.2	1.9	1.7	4.7	5.0	4.1
650	1.8	1.6	1.2	2.0	1.9	1.5	4.7	4.7	3.8
670	2.2	2.2	1.6	1.9	2.3	1.4	5.0	5.1	4.7
690	.	.	.	1.8	2.9	1.6	7.1	7.6	6.5
710	.	.	.	.	.	.	12.8	13.6	11.7
730	.	.	.	.	.	.	16.4	22.0	22.0
750	.	.	.	.	.	.	17.2	23.2	26.6
770	.	.	.	.	.	.	17.3	25.3	27.0
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

DIAGRAM 58

NO.1 STAND OF SCOTCH PINE MATURE (FOR DETAILS SEE TABLE 4, PLOT 1) / P, I 1 / JUNE 24, 1955, SA 34 TO 37 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)

NO.2 STAND OF BIRCH MATURE (FOR DETAILS SEE TABLE 4, PLOT 3) P, I 1 / JUNE 24, 1955, SA 34 TO 37 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)

NO.3 STAND OF SPRUCE MATURE (FOR DETAILS SEE TABLE 4, PLOT 2) P, I 1 / JUNE 24, 1955, SA 34 TO 37 / LENINGRAD / ARCYES58OSD, (BEIOSV59AFL)

DIAGRAM 59

NO.1 STAND OF SCOTCH PINE MATURE (FOR DETAILS SEE TABLE 4, PLOT 1) / P, I 1 / JULY 19, 1955 / LENINGRAD / ARCYES58OSD

NO.2 STAND OF BIRCH MATURE (FOR DETAILS SEE TABLE 4, PLOT 3) P, I 1 / JULY 19, 1955 / LENINGRAD / ARCYES58OSD

NO.3 STAND OF ASPEN MATURE (FOR DETAILS SEE TABLE 4, PLOT 4) P, I 1 / JULY 19, 1955 / LENINGRAD / ARCYES58OSD

DIAGRAM 60

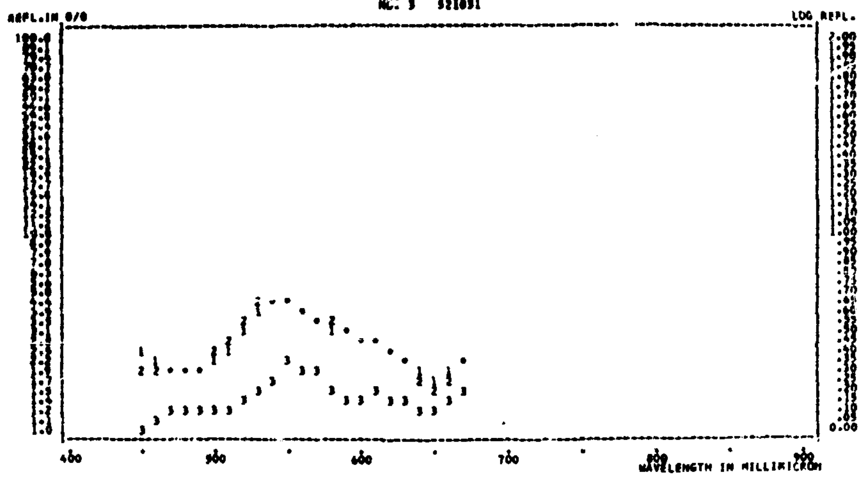
NO.1 STAND OF SCOTCH PINE (FOR DETAILS SEE TABLE 4, PLOT 1) P, I 5 / AUGUST 11, 1955, SA 36 TO 38 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)

NO.2 STAND OF BIRCH (FOR DETAILS SEE TABLE 4, PLOT 3) / P, I 5 / AUGUST 11, 1955, SA 36 TO 38 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)

NO.3 STAND OF ASPEN (FOR DETAILS SEE TABLE 4, PLOT 4) / P, I 5 / AUGUST 11, 1955, SA 36 TO 38 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)

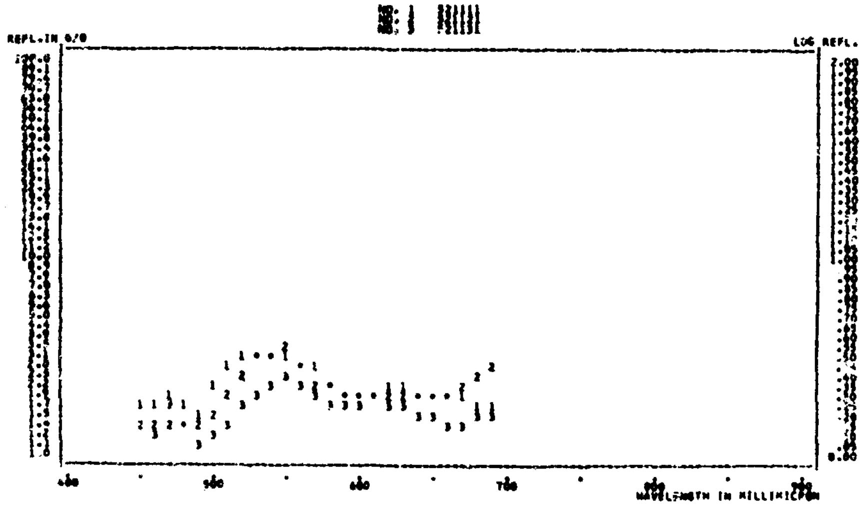
SPECTRAL REFLECTANCE CURVES

DIAGRAM [illegible]



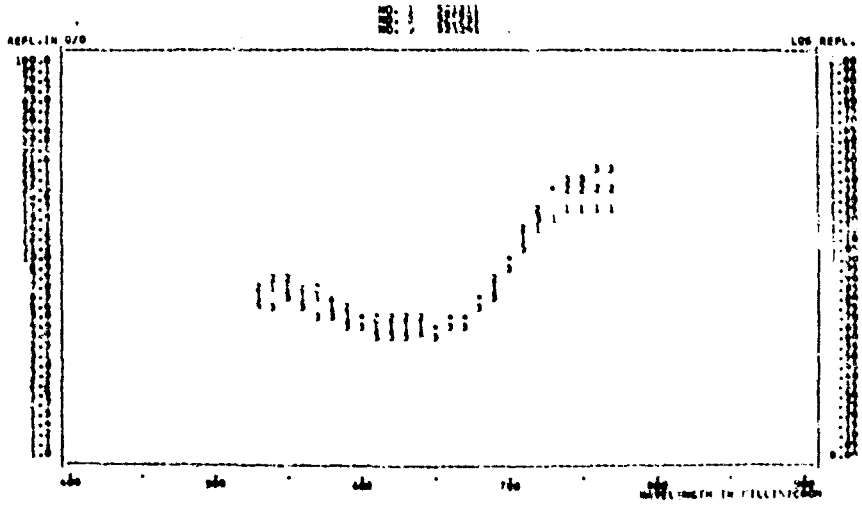
SPECTRAL REFLECTANCE CURVES

DIAGRAM [illegible]



SPECTRAL REFLECTANCE CURVES

DIAGRAM [illegible]



WAVE-LENGTH MMICR.	DIAGRAM 61 NO.1	DIAGRAM 61 NO.2	DIAGRAM 61 NO.3	DIAGRAM 62 NO.1	DIAGRAM 62 NO.2	DIAGRAM 62 NO.3	DIAGRAM 63 NO.1	DIAGRAM 63 NO.2	DIAGRAM 63 NO.3
400	.	.	.	.	4.5	5.0	4.4	.	.
430	.	.	.	.	5.2	5.7	5.5	.	.
450	4.7	7.0	6.0	.	5.4	5.7	6.1	6.8	.
470	4.3	8.7	7.0	.	5.4	5.7	6.7	7.5	.
490	3.7	10.3	8.7	.	5.5	5.8	7.2	9.0	.
510	6.7	11.7	9.7	.	6.0	6.5	9.3	10.5	.
530	9.1	13.0	10.5	.	7.1	8.0	11.5	12.5	12.1
550	9.3	14.0	12.0	.	11.0	11.2	11.2	13.5	11.8
570	8.2	15.0	13.2	9.2	10.4	7.2	9.3	13.7	11.6
590	7.8	15.8	14.2	8.7	8.0	4.9	8.0	13.5	12.5
610	7.5	16.2	15.3	7.7	10.1	4.2	7.5	13.0	13.5
630	6.5	16.2	16.2	7.4	9.5	4.0	6.8	12.0	14.6
650	5.1	15.9	17.1	6.3	7.5	3.6	5.5	10.5	17.5
670	4.0	15.9	18.0	5.7	5.0	3.7	4.7	10.2	21.8
690	5.3	16.0	19.1	7.1	9.0	9.0	10.5	16.0	28.5
710	14.0	16.4	20.5	15.0	20.0	25.5	39.5	26.5	35.5
730	28.2	17.1	21.9	32.2	52.6	58.0	58.0	36.5	38.5
750	44.3	18.0	23.7	33.4	70.5	73.8	64.4	56.7	39.1
770	48.8	18.8	25.5	33.5	72.5	76.5	65.0	59.5	39.2
790	50.1	19.8	26.8	.	73.0	77.2	65.2	60.4	39.2
810	50.4	20.7	27.8	.	.	.	.	.	.
830	50.5	21.6	28.9	.	.	.	.	.	.
850	50.6	22.5	30.0	.	.	.	.	.	.
870	50.6	23.0	31.0	.	.	.	.	.	.
890	50.6	23.4	31.7	.	.	.	.	.	.

DIAGRAM 61

NO.1 OATS FLOWERING / G, I 2,(1) / AUGUST 11, 1958, SA 53 / L,VOV / ALEKVA60SDP

NO.2 RYE RIPE / G, I 2,(1) / AUGUST 11, 1958, SA 48 / L,VOV / ALEKVA60SDP

NO.3 RYE STRAW GOLDEN-YELLOW / G, I 2,(1) / SEPTEMBER 29, 1958, SA 36 / L,VOV / ALEKVA60SDP

DIAGRAM 62

NO.1 UPLAND MEADOW P, I 5 / AUGUST 9, 1955 / LENINGRAD / ARCYES58OSD, (BELOSV59AFL)

NO.2 RYE FLOWERING, H 1.3 / P, I 3 / JULY 5, 1957, SA 56 / TOMSK / BELOSV59AFL

NO.3 MEADOW H 0.6, COVERED BY GRASSES AND BROADLEAVED HERBS / P, I 3 / JULY 8, 1957, SA 35 / TOMSK / BELOSV59AFL

DIAGRAM 63

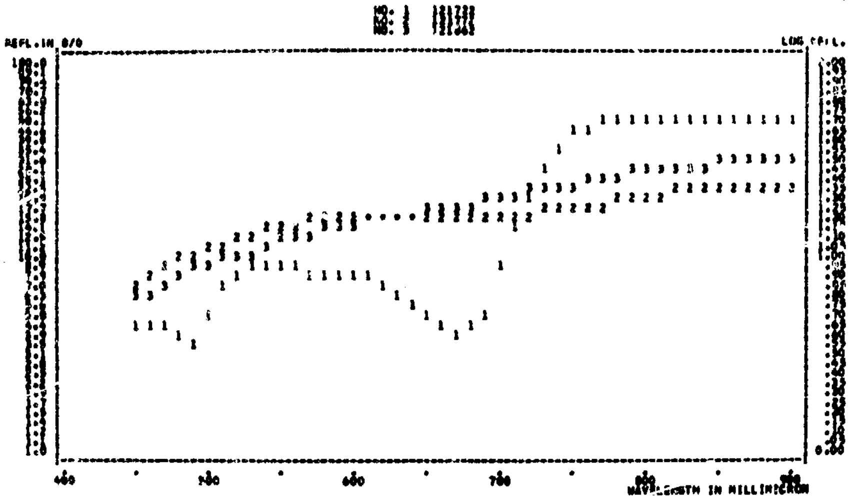
NO.1 MEADOW 80 PERCENT GRASS SPECIES, 15 PERCENT CLOVER, 5 PERCENT CROWFOOT / G, I 1.3 / AUGUST 31, 1957, SA 41 / TOMSK / BELOSV59AFL

NO.2 ID. FRESHLY CUT

NO.3 HAY DRY / G, I 1.3 / 1957, SA 36 / TOMSK / BELOSV59AFL

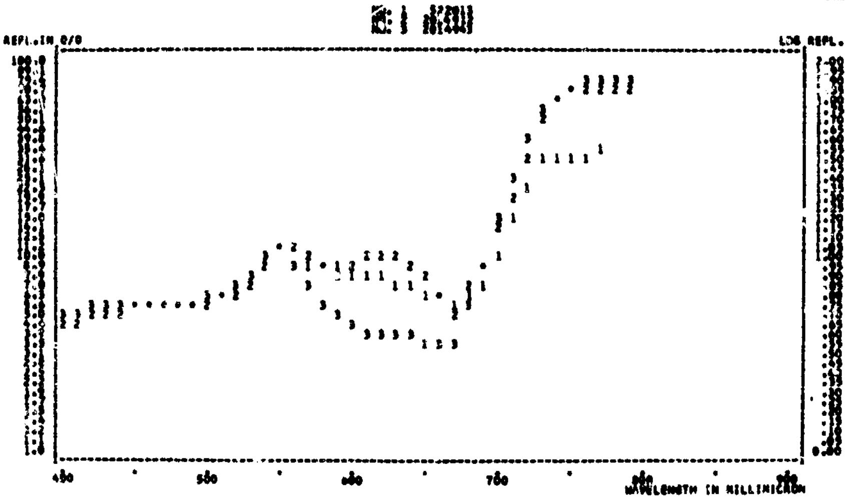
SPECTRAL REFLECTANCE CURVES

DIAGRAM 61



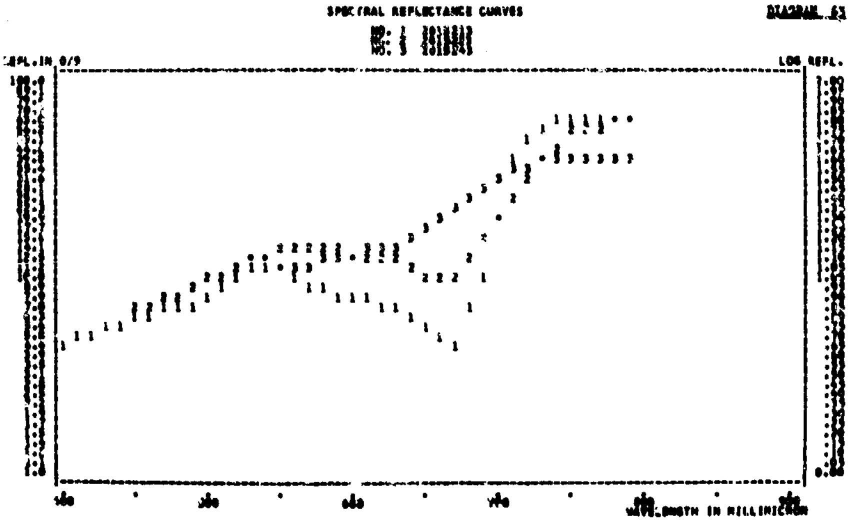
SPECTRAL REFLECTANCE CURVES

DIAGRAM 62



SPECTRAL REFLECTANCE CURVES

DIAGRAM 63



WAVE-LENGTH MMICR.	DIAGRAM 64 NO.1	NO.2	NO.3	DIAGRAM 65 NO.1	NO.2	NO.3	DIAGRAM 66 NO.1	NO.2	NO.3
400	3.3	1.2	2.2	.	.	.	.	.	.
430	3.5	1.3	2.5	.	.	.	.	.	.
450	3.8	1.3	2.7	.	.	.	.	.	.
470	4.1	1.5	2.8	.	.	.	.	.	.
490	4.5	1.7	3.1	.	.	.	.	.	.
510	5.7	2.0	4.2	.	.	.	.	.	.
530	9.7	3.0	6.0	.	.	.	.	.	.
550	12.3	4.5	6.8	.	16.2	10.0	8.3	5.1	.
570	11.0	3.8	7.0	6.3	13.1	5.8	7.5	4.8	.
590	8.2	3.3	5.5	6.9	11.3	4.5	6.7	4.2	.
610	6.5	3.2	5.2	7.4	10.7	3.8	5.8	3.7	.
630	5.3	3.0	5.4	8.1	10.1	3.5	5.1	3.2	.
650	5.2	2.8	5.5	8.4	9.0	3.0	4.7	3.0	.
670	6.7	2.2	6.1	8.0	10.5	3.2	4.6	2.9	.
690	10.2	3.5	8.8	7.8	13.5	5.2	7.7	5.0	.
710	15.0	3.7	14.2	9.4	19.3	9.7	30.5	13.8	.
730	42.0	13.7	17.0	11.7	30.0	62.0	42.2	27.5	.
750	55.0	18.2	17.1	12.7	51.0	76.7	45.0	31.7	.
770	60.7	21.[illegible]	17.3	13.6	53.2	78.5	.	.	.
790	64.8	23.2	17.5	.	53.0	78.8	.	.	.
810	67.2	25.2	.	.	.	.	.	.	.
830	69.0	26.0	.	.	.	.	.	.	.
850	70.2	26.5	.	.	.	.	.	.	.
870	71.0	27.5	.	.	.	.	.	.	.
890	71.4	28.7	.	.	.	.	.	.	.

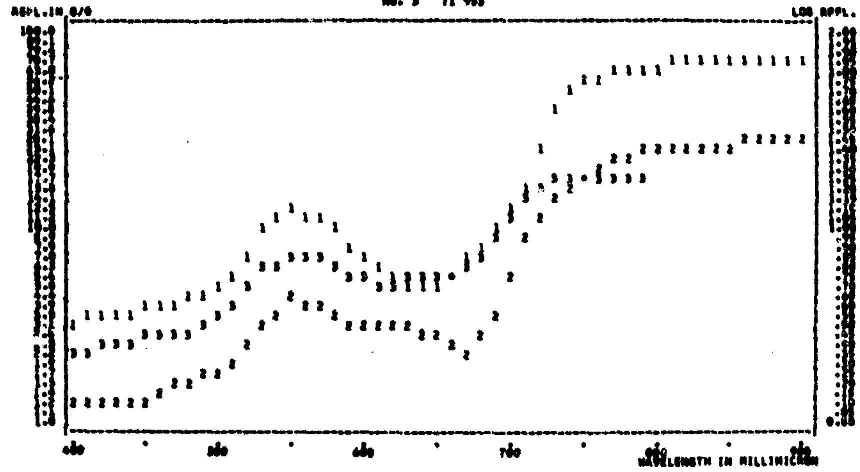
DIAGRAM 64
NO.1 UPLAND MEADOW PRONAK49IRA
NO.2 MEADOW SWAMPY, WITH SEDGES / PRONAK49IRA
NO.3 FALLOW GREEN / PRONAK49IRA

DIAGRAM 65
NO.1 PEAT (DIGGING AREA) P, I 5 / AUGUST 9, 1955, SA 40 TO 41
LENINGRAD / ARCYES58OSD, (BELOSV59AFL)
NO.2 PEAT-MOSS BOG P, I 3 / SEPTEMBER 10, 1957, SA 40 /
TOMSK / BELOSV59AFL
NO.3 PEAT-MOSS SEDGE BOG P, I 3 / JULY 8, 1957, SA 35 /
TOMSK / BELOSV59AFL

DIAGRAM 66
NO.1 LOW MOOR WITH SEDGES, MOIST / P, I 3 / JULY 11, 1958,
SA 53 / L,VOV / ALEKVA60SDP
NO.2 ID. WET

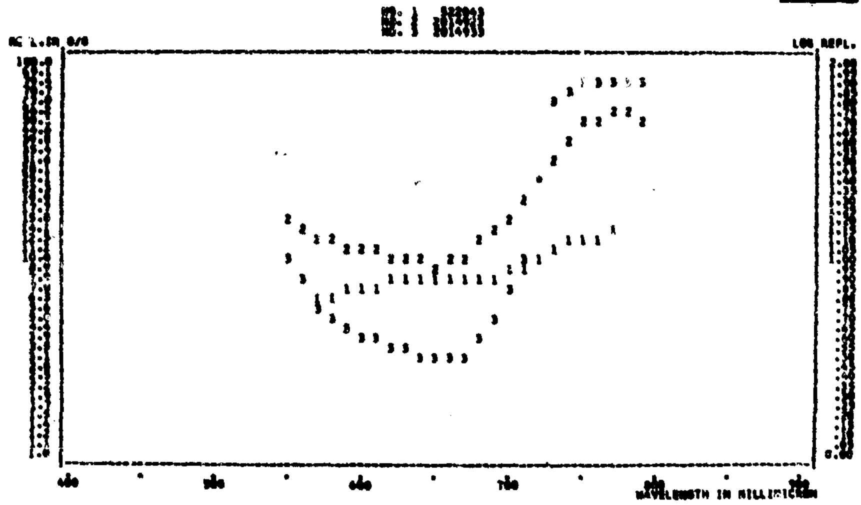
SPECTRAL REFLECTANCE CURVES

DIAGRAM 64



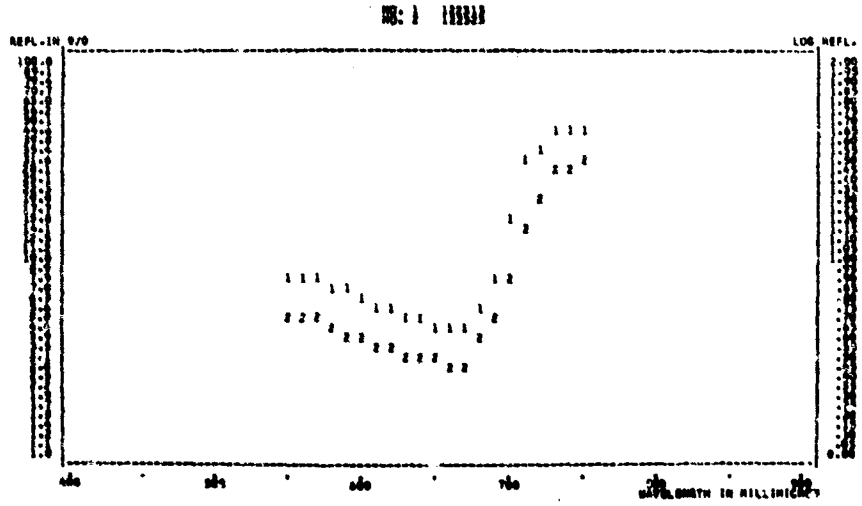
SPECTRAL REFLECTANCE CURVES

DIAGRAM 65



SPECTRAL REFLECTANCE CURVES

DIAGRAM 66



WAVE-LENGTH MMICR.	DIAGRAM 67 NO.1	NO.2	NO.3	DIAGRAM 68 NO.1	NO.2	NO.3	DIAGRAM 69 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	.	.	.	1.5	2.4	.	.	.	.
450	.	.	.	2.4	1.3	.	.	.	.
470	.	.	.	3.0	1.3	.	.	.	.
490	22.3	19.2	24.5	3.9	1.7	.	.	.	.
510	27.3	21.2	23.0	6.3	2.9	.	.	.	.
530	30.8	24.6	22.0	7.6	4.5	.	.	.	.
550	33.0	27.1	23.5	8.8	5.7	.	6.5	6.0	.
570	33.1	28.0	25.8	9.5	6.2	.	6.8	5.2	.
590	34.0	29.0	27.8	6.7	5.7	.	5.6	4.7	.
610	36.0	29.8	28.0	4.1	5.3	.	5.0	4.5	.
630	38.8	30.6	28.0	3.9	4.5	.	5.0	3.5	.
650	41.6	31.0	26.8	4.2	3.7	.	6.0	2.9	.
670	44.8	30.8	25.8	4.2	2.5	.	5.3	1.9	.
690	48.2	30.2	26.0	4.2	1.7	.	4.8	1.2	.
710	51.5	29.5	27.0	.	.	.	2.5	1.1	.
730	54.0	29.5	29.0	.	.	.	6.0	4.2	.
750	56.8	31.0	33.2	.	.	.	9.3	8.0	.
770	58.4	33.0	39.0	.	.	.	.	.	.
790	60.0	33.6	44.5	.	.	.	.	.	.
810	60.6	34.8	49.8	.	.	.	.	.	.
830	60.0	36.2	51.6	.	.	.	.	.	.
850	59.8	38.0	51.0	.	.	.	.	.	.
870	59.6	39.0	47.0	.	.	.	.	.	.
890	59.4	39.2	44.8	.	.	.	.	.	.

DIAGRAM 67
NO.1 COTTON BEFORE IRRIGATION / P, I 7 / JULY 1958 TO 1960 / ASHKHABAD / ARCYES62ISJ
NO.2 ID. AFTER IRRIGATION
NO.3 VINEYARD P, I 7 / JULY 1958 TO 1960 / ASHKHABAD / ARCYES62ISJ

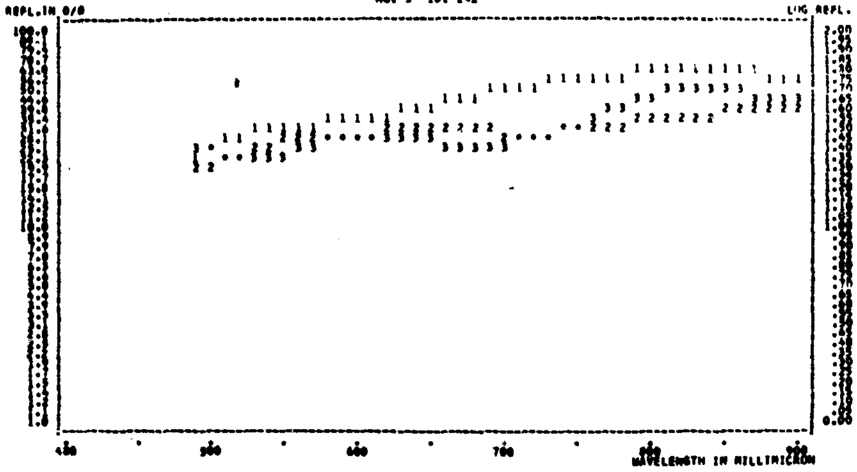
DIAGRAM 68
NO.1 RUDERAL HERBS ON FLOOD PLAIN / G, I 1 / (SUMMER) 1958 TO 1960 / NARYNKA RIVER*/ ARCYES62ISJ
NO.2 COUCH GRASS ASSOCIATION IN DRY RIVER BED (WADI) / G, I 1 / (SUMMER) 1958 TO 1960 / NARYNKA RIVER / ARCYES62ISJ

DIAGRAM 69
NO.1 WATER IN A DEAD RIVER COURSE, DEPTH 1 TO 2 M, BROWNISH, BOTTOM MUDDY AND DARK / P, I 3, DM 7,0 / JULY 5, 1957 / TOMSK / BELOSV59AFL
NO.2 ID. DM 7,180

*Caspian Lowland

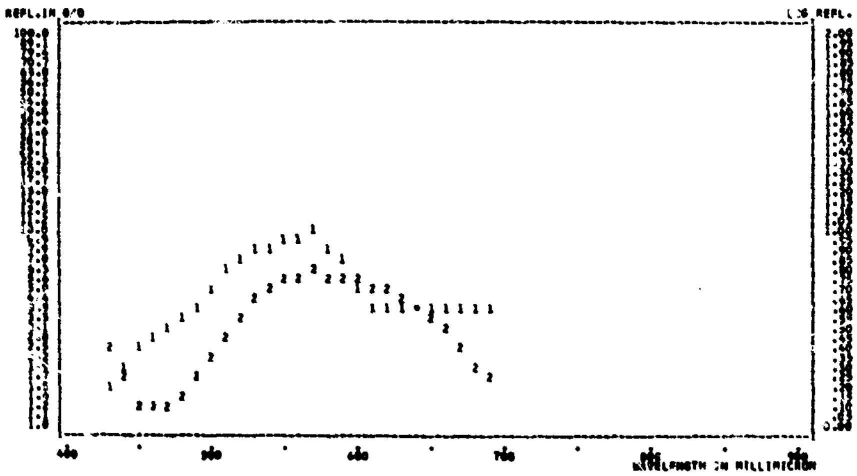
SPECTRAL REFLECTANCE CURVES

DIAGRAM 67



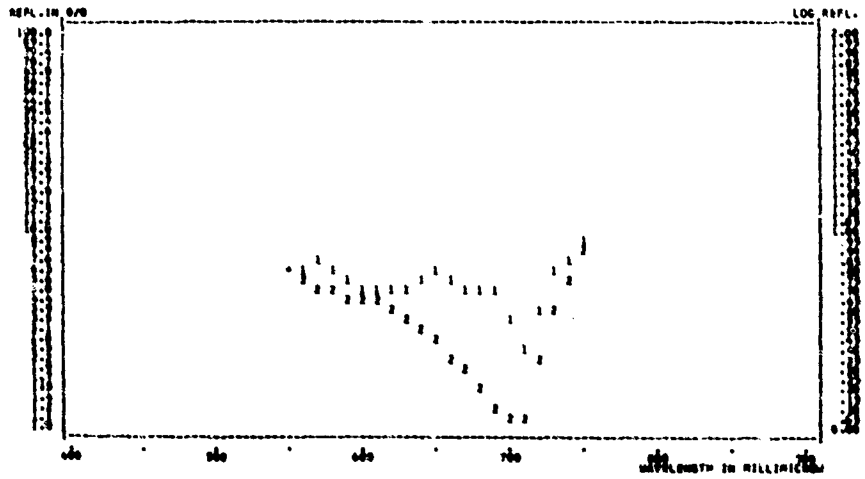
SPECTRAL REFLECTANCE CURVES

DIAGRAM 68



SPECTRAL REFLECTANCE CURVES

DIAGRAM 69



WAVE-LENGTH MMICR.	DIAGRAM 70 NO.1	NO.2	NO.3	DIAGRAM 71 NO.1	NO.2	NO.3	DIAGRAM 72 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	6.7	3.3	2.3	11.6	6.1	4.6	6.8	5.3	.
450	8.0	4.2	3.4	11.8	6.2	7.4	7.0	5.7	.
470	9.3	4.3	3.4	12.8	6.7	8.1	7.5	6.2	.
490	10.1	3.8	2.8	13.5	7.3	8.0	8.5	6.8	.
510	10.4	3.8	3.2	14.5	7.9	9.2	9.4	7.5	.
530	11.0	5.8	4.6	15.4	9.5	10.0	10.1	8.1	.
550	12.0	6.4	5.2	15.8	10.9	9.4	11.0	8.6	.
570	12.5	6.6	5.5	16.2	11.5	9.9	11.0	8.4	.
590	12.5	6.4	5.2	16.9	11.7	11.3	10.0	7.6	.
610	13.0	6.8	5.3	17.6	11.7	12.5	9.5	7.4	.
630	13.6	7.6	5.0	18.5	11.6	12.6	9.3	7.4	.
650	14.0	7.7	5.2	19.6	12.4	12.6	9.2	7.2	.
670	13.7	7.8	5.8	20.3	13.2	12.0	9.2	6.8	.
690	.	.	.	.	.	.	8.6	6.3	.
710	.	.	.	.	.	.	.	.	.
730	.	.	.	.	.	.	.	.	.
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

DIAGRAM 70
NO.1 MEADOW CHESTNUT SOIL FRESH GROUNDWATER / G, I 1 / (SUMMER) / SARPINIAN LAKES*/ ARCYES61SEL
NO.2 CRESTED WHEAT GRASS FRESH GROUNDWATER / G, I 1 / (SUMMER) / SARPINIAN LAKES*/ ARCYES61SEL
NO.3 COUCH GRASS FRESH GROUNDWATER / G, I 1 / (SUMMER) / SARPINIAN LAKES*/ ARCYES61SEL

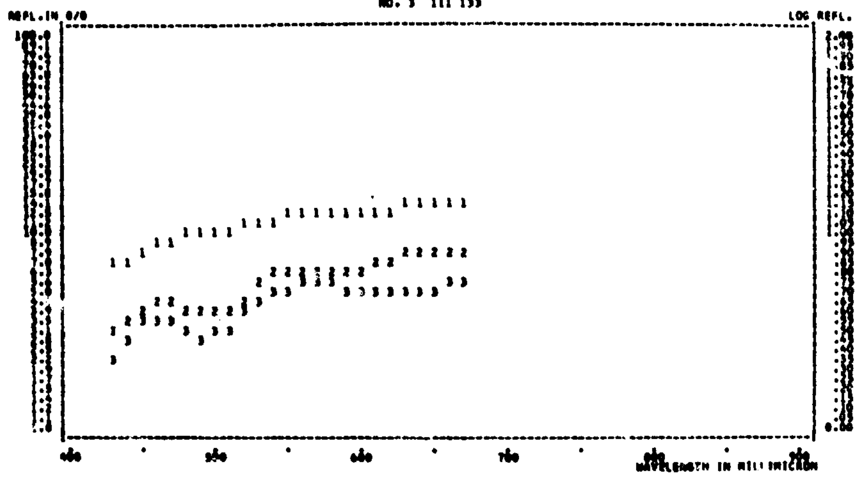
DIAGRAM 71
NO.1 MEADOW-CHESTNUT SOIL SALINE, SALINE GROUNDWATER / G, I 1 / (SUMMER) / SARPINIAN LAKES*/ ARCYES61SEL
NO.2 WORMWOOD (PROBABLY BLACK POLYN), SALINE GROUNDWATER G, I 1 / (SUMMER) / SARPINIAN LAKES*/ ARCYES61SEL
NO.3 SALT-TOLERATING COUCH GRASS G, I 1 / (SUMMER) / SARPINIAN LAKES*/ ARCYES61SEL

DIAGRAM 72
NO.1 WHITE POLYN SALINE GROUNDWATER / G, I 1 / (SUMMER) 1958 TO 1960 / TAJSOJGAN SANDS*/ ARCYES62ISJ
NO.2 SAND POLYN FRESH GROUNDWATER / G, I 1 / (SUMMER) 1958 TO 1960 / TAJSOJGAN SANDS*/ ARCYES62ISJ

*Caspian Lowland

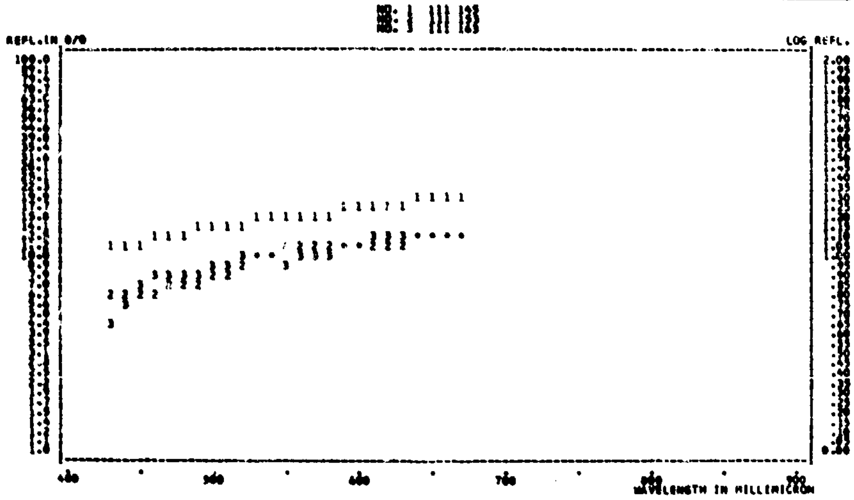
SPECTRAL REFLECTANCE CURVES

DIAGRAM 70



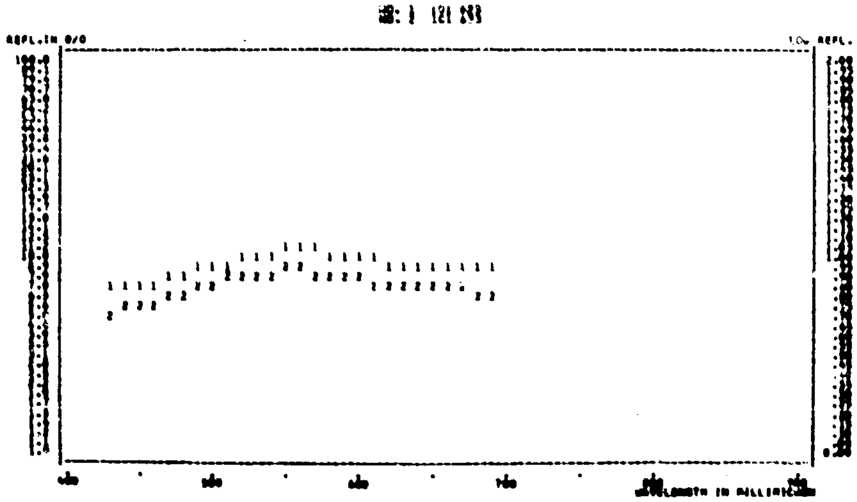
SPECTRAL REFLECTANCE CURVES

DIAGRAM 71



SPECTRAL REFLECTANCE CURVES

DIAGRAM 72



WAVE-LENGTH MMICR.	DIAGRAM 73 NO.1	NO.2	NO.3	DIAGRAM 74 NO.1	NO.2	NO.3	DIAGRAM 75 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	14.5	3.8	1.9	7.9	2.2	.	8.5	4.5	3.8
450	16.5	4.8	3.1	8.6	3.0	.	9.5	5.2	4.2
470	18.7	5.8	4.1	9.5	3.6	.	10.7	5.7	5.0
490	20.5	6.7	4.9	10.2	3.8	.	11.7	6.3	5.5
510	21.7	8.0	5.8	12.3	4.5	.	12.6	7.0	6.3
530	22.6	9.2	6.9	13.7	6.1	.	13.6	7.5	6.8
550	23.1	9.7	8.2	13.8	8.2	.	14.5	8.0	7.2
570	23.9	9.2	8.2	14.5	8.5	.	15.5	7.8	7.2
590	25.4	8.0	7.8	15.5	6.9	.	15.9	7.0	6.3
610	26.8	6.7	7.5	16.0	6.2	.	16.0	6.8	6.0
630	27.9	5.7	7.7	16.0	7.0	.	15.4	6.6	5.5
650	28.5	5.0	7.0	15.7	7.6	.	14.5	6.3	5.2
670	29.0	4.3	6.0	15.3	7.6	.	14.0	5.7	4.9
690	29.3	3.8	5.0	14.8	7.5	.	14.0	5.1	4.2
710	.	.	.	.	.	.	.	.	.
730	.	.	.	.	.	.	.	.	.
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

DIAGRAM 73
NO.1 SAND TOP OF BARKHANS / G, I 1 / NARYNKA RIVER* / ARCYES62ISJ
NO.2 REED G, I 1 / NARYNKA RIVER* / ARCYES62ISJ
NO.3 TAMARISK G, I 1 / NARYNKA RIVER* / ARCYES62ISJ

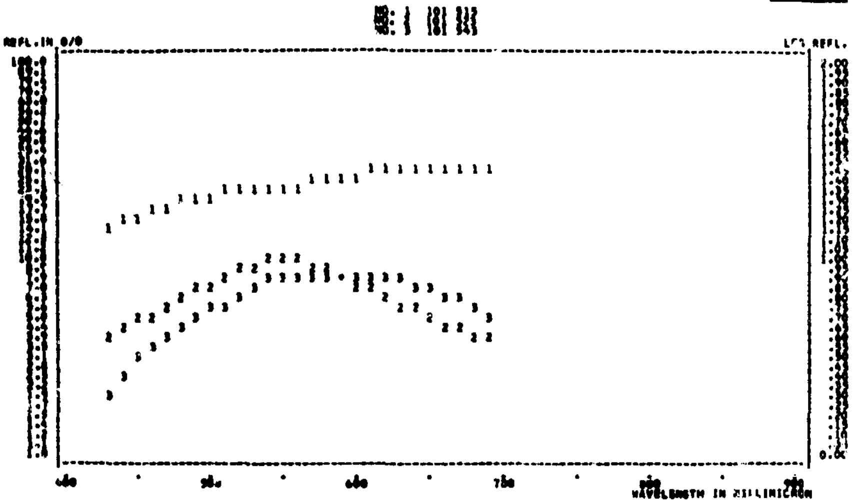
DIAGRAM 74
NO.1 BIJURGUN ASSOCIATION UPLAND / G, I 1 / (SUMMER) 1958 TO 1960 / NARYNKA RIVER* / ARCYES62ISJ
NO.2 WHITE POLYN ASSOCIATION WITH MESOPHYTES, IN ROUND LIMANS / G, I 1 / (SUMMER) 1958 TO 1960 / NARYNKA RIVER */ ARCYES62ISJ

DIAGRAM 75
NO.1 ANNUAL SALTWORT IN SALTPAN, SALINE GROUNDWATER / G, I 1 (SUMMER) 1958 TO 1960 / TAJSOJGAN SANDS* / ARCYES62ISJ
NO.2 WOODREED AND BLUE GRASS FRESH GROUNDWATER / G, I 1 / (SUMMER) 1958 TO 1960 / TAJSOJGAN SANDS* / ARCYES62ISJ
NO.3 LICORICE FRESH GROUNDWATER / G, I 1 / (SUMMER) 1958 TO 1960 / TAJSOJGAN SANDS* / ARCYES62ISJ

* Caspian Lowland

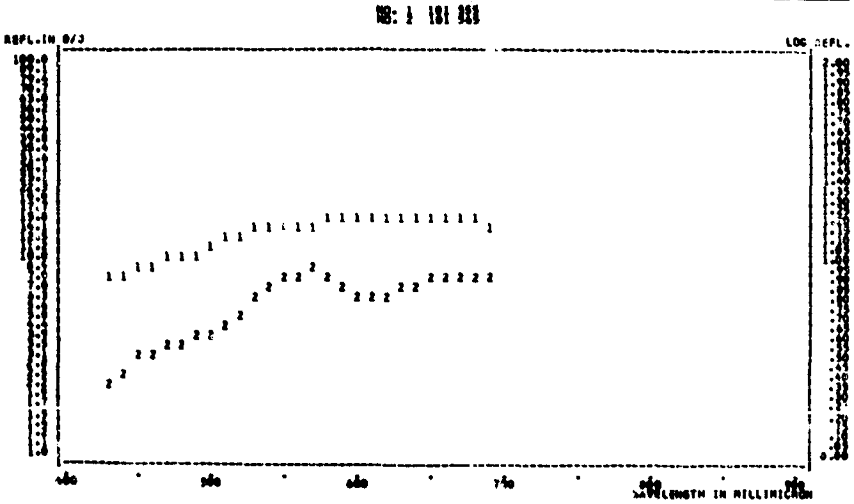
SPECTRAL REFLECTANCE CURVES

DIAGRAM 73



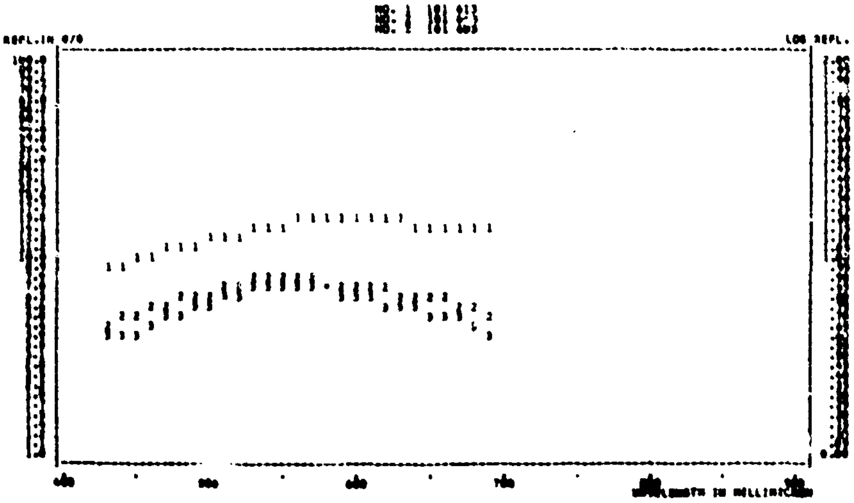
SPECTRAL REFLECTANCE CURVES

DIAGRAM 74



SPECTRAL REFLECTANCE CURVES

DIAGRAM 75



WAVE-LENGTH MMICR.	DIAGRAM 76 NO.1	NO.2	NO.3	DIAGRAM 77 NO.1	NO.2	NO.3	DIAGRAM 78 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	89.0	83.5	74.8	6.5	2.4	.	2.4	5.3	.
450	86.1	80.2	75.0	6.9	2.4	.	2.8	6.0	.
470	87.2	75.5	75.0	8.5	2.4	.	2.4	6.0	.
490	86.2	73.1	75.0	10.6	2.4	.	2.3	5.6	.
510	86.4	71.1	74.6	12.5	2.4	.	2.0	5.0	.
530	86.0	68.8	74.3	12.7	2.4	.	2.5	4.7	.
550	87.0	68.3	74.1	14.0	2.4	.	3.4	4.5	.
570	86.8	69.1	72.8	14.6	2.4	.	4.0	4.3	.
590	83.1	71.4	70.4	15.5	2.5	.	4.8	4.7	.
610	85.0	72.6	68.2	16.7	2.5	.	7.5	4.7	.
630	79.3	68.0	67.3	18.5	2.4	.	9.9	4.7	.
650	80.3	66.2	67.9	20.0	2.3	.	12.6	4.6	.
670	80.7	64.6	67.8	21.1	2.2	.	13.3	4.5	.
690	.	.	.	.	.	.	.	.	.
710	.	.	.	.	.	.	.	.	.
730	.	.	.	.	.	.	.	.	.
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

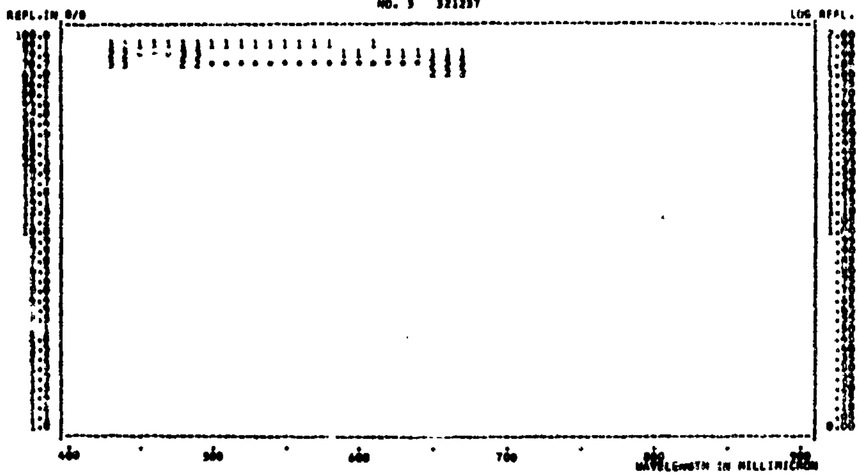
DIAGRAM 76
NO.1 SODIUM CARBONATE (NA2CO3) / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.2 SODIUM CHLORIDE (NACL) / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.3 POTASSIUM HYDROGENE SULFATE (KHSO4) / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS63PFT

DIAGRAM 77
NO.1 FULVIC ACID L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.2 HUMIC ACID L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT

DIAGRAM 78
NO.1 HEMATITE (IRON-III-OXIDE, FE2O3) / L, I 1 / NORTHERN KAZAKHSTAN
NO.2 MAGNETITE (IRON-II,III-OXIDE, FE3O4) / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT

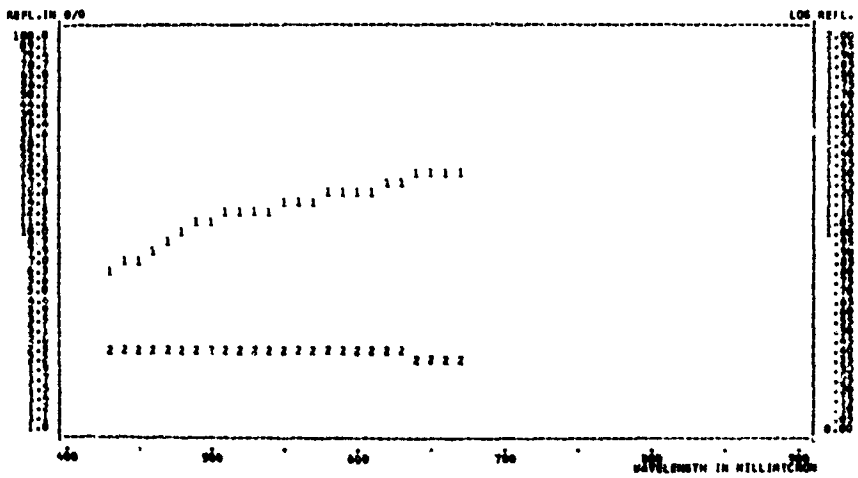
SPECTRAL REFLECTANCE CURVES

DIAGRAM 76



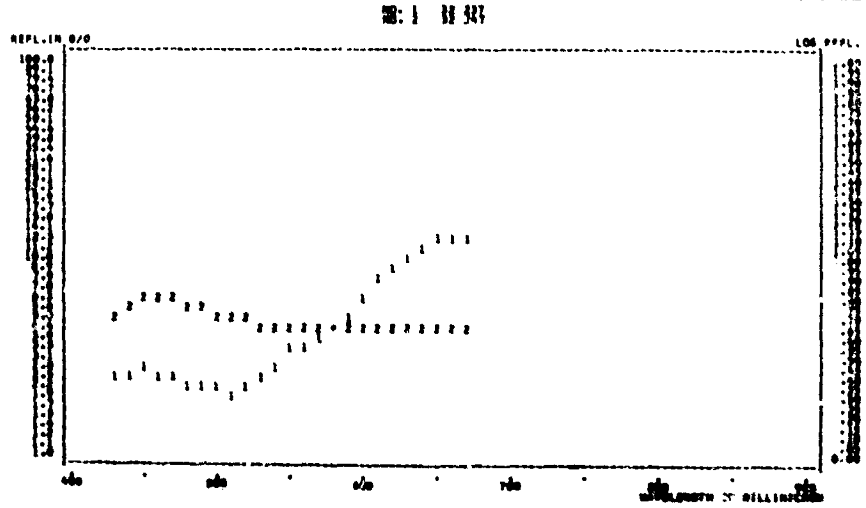
SPECTRAL REFLECTANCE CURVES

DIAGRAM 77



SPECTRAL REFLECTANCE CURVES

DIAGRAM 78



WAVE-LENGTH MMICR.	DIAGRAM 79 NO.1	NO.2	NO.3	DIAGRAM 80 NO.1	NO.2	NO.3	DIAGRAM 81 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	93.0	7.4	59.6	58.8	10.0	14.5	.	.	.
450	92.8	7.4	59.1	60.0	10.5	16.5	14.6	7.0	.
470	92.9	7.4	59.0	62.4	11.5	18.5	15.5	7.4	.
490	92.9	7.4	59.6	64.5	12.0	25.0	17.0	8.2	.
510	92.9	7.4	60.0	65.4	13.6	32.0	20.0	9.5	.
530	92.9	7.4	60.3	68.0	16.0	35.2	22.9	11.3	.
550	93.0	7.4	60.3	71.2	18.0	35.2	25.3	13.0	.
570	93.0	7.4	60.6	74.9	20.8	35.4	27.5	14.7	.
590	93.3	7.4	60.5	79.0	23.0	35.8	28.8	15.5	.
610	93.5	7.4	60.4	81.6	26.5	36.0	28.7	15.4	.
630	93.5	7.4	60.3	82.2	29.0	36.2	28.2	15.5	.
650	93.5	7.4	60.3	80.9	32.5	36.5	29.0	16.4	.
670	93.4	7.4	60.0	78.0	33.2	37.2	31.1	16.5	.
690	.	.	.	.	.	.	31.5	16.1	.
710	.	.	.	.	.	.	31.5	16.0	.
730	.	.	.	.	.	.	31.6	16.6	.
750	.	.	.	.	.	.	32.3	17.7	.
770	.	.	.	.	.	.	32.8	17.8	.
790	.	.	.	.	.	.	33.4	17.5	.
810	.	.	.	.	.	.	34.1	18.4	.
830	.	.	.	.	.	.	35.0	19.7	.
850	.	.	.	.	.	.	36.1	20.4	.
870	.	.	.	.	.	.	36.7	20.8	.
890	.	.	.	.	.	.	37.2	21.1	.

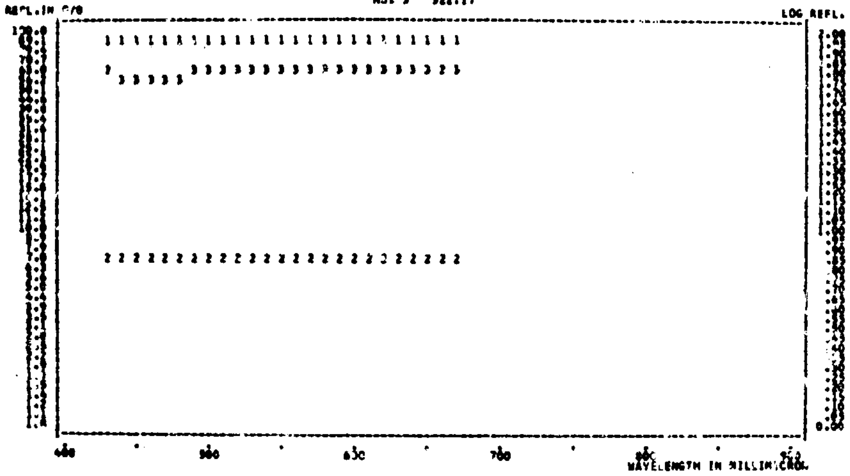
DIAGRAM 79
NO.1 QUARTZ FRACTION * SMALLER THAN 0.1 MM / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.2 BIOTITE FRACTION * SMALLER THAN 0.1 MM / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.3 MUSCOVITE FRACTION * SMALLER THAN 0.1 MM / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT

DIAGRAM 80
NO.1 MICROCLINE FRACTION * SMALLER THAN 0.1 MM / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.2 GARNET FRACTION * SMALLER THAN 0.1 MM / L, I 1 / NORTHERN KAZAKHSTAN / BELDIN59ZSJ
NO.3 EPIDOTE FRACTION * SMALLER THAN 0.1 MM / L, I 1 / NORTHERN KAZAKHSTAN / BELDIN59ZSJ

DIAGRAM 81
NO.1 SAND DRY, YELLOW / G, I 2,(1) / JULY 17, 1958, SA 60 / ALEKVA60SDP
NO.2 ID. WET, YELLOW

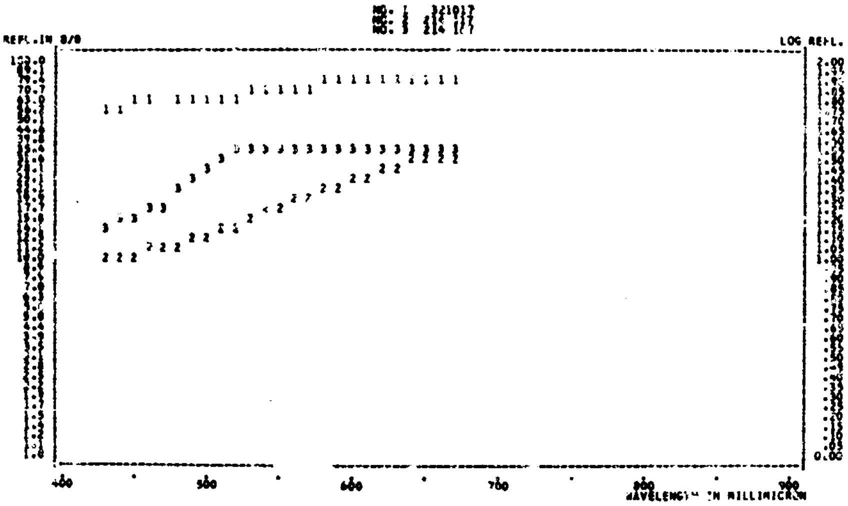
SPECTRAL REFLECTANCE CURVES

DIAGRAM 79



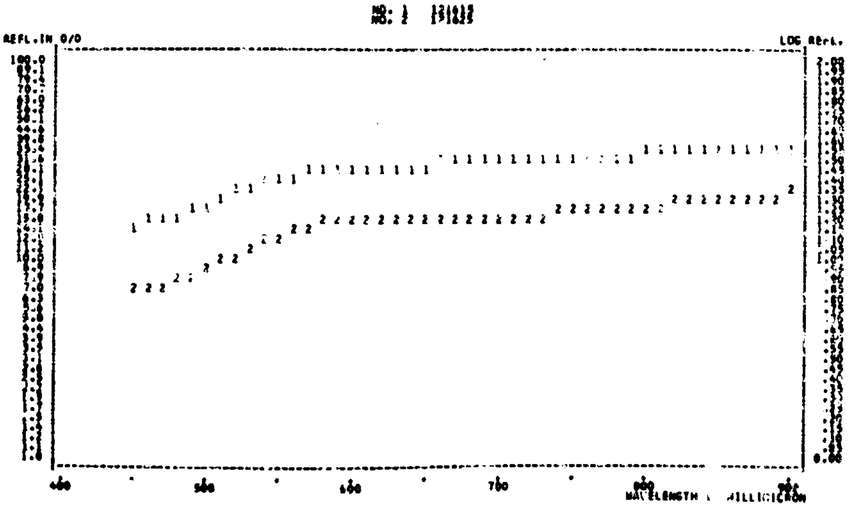
SPECTRAL REFLECTANCE CURVES

DIAGRAM 80



SPECTRAL REFLECTANCE CURVES

DIAGRAM 81



WAVE-LENGTH MMICR.	DIAGRAM 82			DIAGRAM 83			DIAGRAM 84		
	NO.1	NO.2	NO.3	NO.1	NO.2	NO.3	NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	58.8	39.3	30.2	93.0	77.3	61.3	7.4	5.8	4.4
450	60.0	39.8	31.3	92.6	77.3	61.3	7.4	5.8	4.4
470	62.4	42.0	32.2	92.9	77.0	61.3	7.4	5.8	4.4
490	64.5	44.5	34.0	92.9	77.0	61.4	7.4	5.8	4.4
510	65.4	46.3	35.7	92.9	77.1	61.5	7.4	5.8	4.4
530	68.0	49.0	37.7	92.9	77.1	61.6	7.4	5.8	4.4
550	71.2	52.2	41.7	93.0	77.1	61.8	7.4	5.8	4.4
570	74.9	57.2	49.1	93.0	77.3	61.9	7.4	5.8	4.4
590	79.0	63.0	54.9	93.3	77.8	62.0	7.4	5.8	4.4
610	81.6	65.6	58.0	93.5	77.8	62.1	7.4	5.8	4.4
630	82.2	66.9	59.7	93.5	77.8	62.2	7.4	5.8	4.4
650	80.9	66.9	60.0	93.5	77.8	62.1	7.4	5.8	4.4
670	78.0	65.0	59.2	93.4	77.9	62.1	7.4	5.8	4.4
690	.	.	.	.	.	.	.	.	.
710	.	.	.	.	.	.	.	.	.
730	.	.	.	.	.	.	.	.	.
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

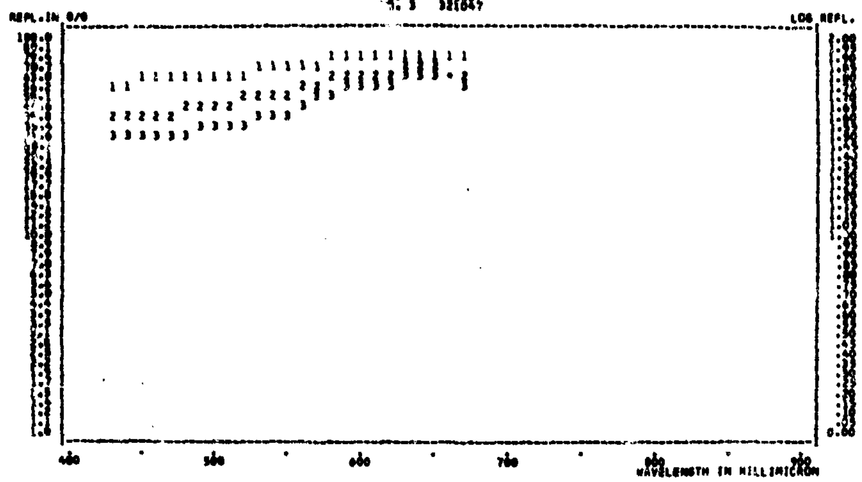
DIAGRAM 82
NO.1 MICROCLINE FRACTION * SMALLER THAN 0.1 MM / L, I 1 /
NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.2 ID. FRACTION * 0.25 TO 0.5 MM
NO.3 ID. FRACTION * 1 TO 3 MM

DIAGRAM 83
NO.1 QUARTZ FRACTION * SMALLER THAN 0.1 MM / L, I 1 /
NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.2 ID. FRACTION * 0.25 TO 0.5 MM
NO.3 ID. FRACTION * 1 TO 3 MM

DIAGRAM 84
NO.1 BIOTITE FRACTION * SMALLER THAN 0.1 MM / L, I 1 /
NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.2 ID. FRACTION * 0.25 TO 0.5 MM
NO.3 ID. FRACTION * 1 TO 3 MM

SPECTRAL REFLECTANCE CURVES

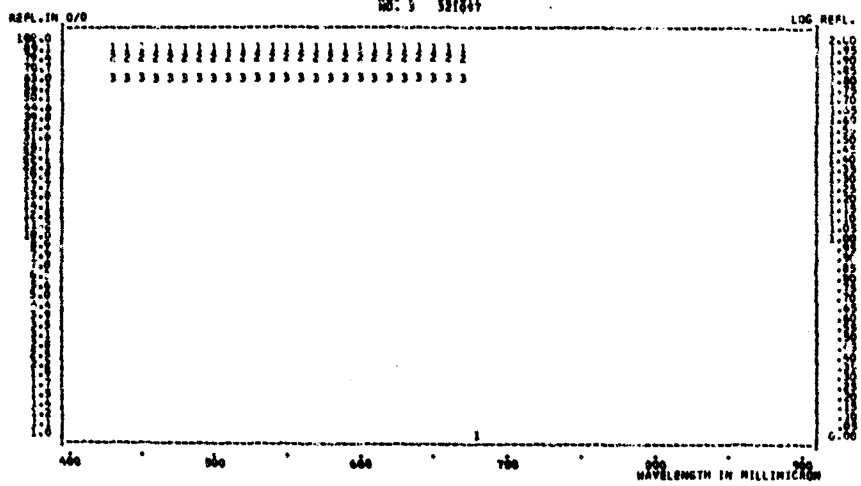
DIAGRAM 82



SPECTRAL REFLECTANCE CURVES

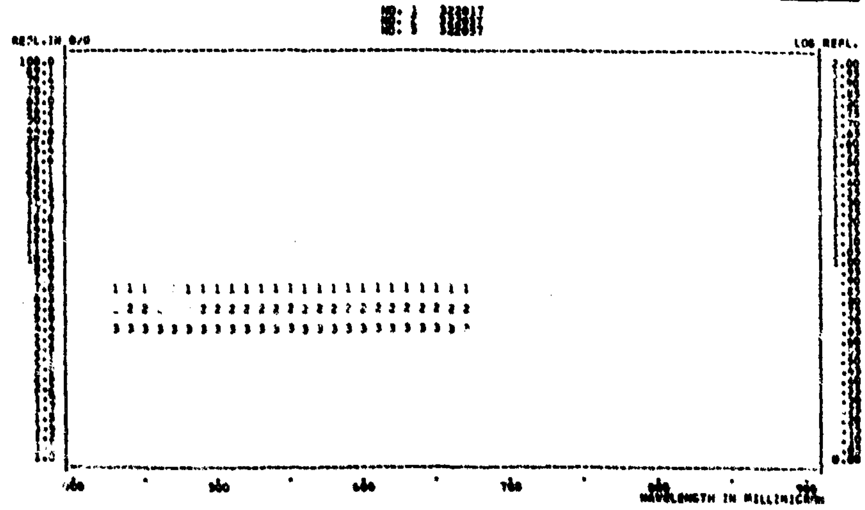
DIAGRAM 83

NO: 1 321057



SPECTRAL REFLECTANCE CURVES

DIAGRAM 84



WAVE-LENGTH MMICR.	DIAGRAM 85 NO.1	NO.2	NO.3	DIAGRAM 86 NO.1	NO.2	NO.3	DIAGRAM 87 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	59.6	39.3	23.2	10.0	3.2	1.2	14.5	7.2	5.2
430	59.1	39.4	23.2	10.5	3.6	1.3	16.5	8.1	5.6
470	59.0	39.3	23.3	11.5	4.0	1.5	18.5	8.0	5.4
490	59.6	39.8	24.0	12.0	4.3	1.7	25.0	11.0	5.9
510	60.0	40.1	24.1	13.6	4.8	1.8	32.0	13.5	6.9
530	60.3	40.2	24.0	16.0	5.2	1.8	35.2	16.0	7.1
550	60.3	40.3	24.2	18.0	5.5	1.8	35.2	15.8	7.1
570	60.6	40.4	24.3	20.8	6.3	2.2	35.4	15.0	6.8
590	60.5	40.3	24.3	23.0	7.5	2.2	35.8	14.8	7.0
610	60.4	40.5	24.2	26.5	9.3	2.6	36.0	14.8	7.0
630	60.3	40.5	24.1	29.0	10.3	2.8	36.2	15.5	7.1
650	60.3	40.5	24.0	32.5	10.8	4.5	36.5	15.8	7.0
670	60.0	40.1	24.0	33.2	11.7	5.2	37.2	16.8	7.6
690	.	.	.	.	.	.	.	.	.
710	.	.	.	.	.	.	.	.	.
730	.	.	.	.	.	.	.	.	.
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

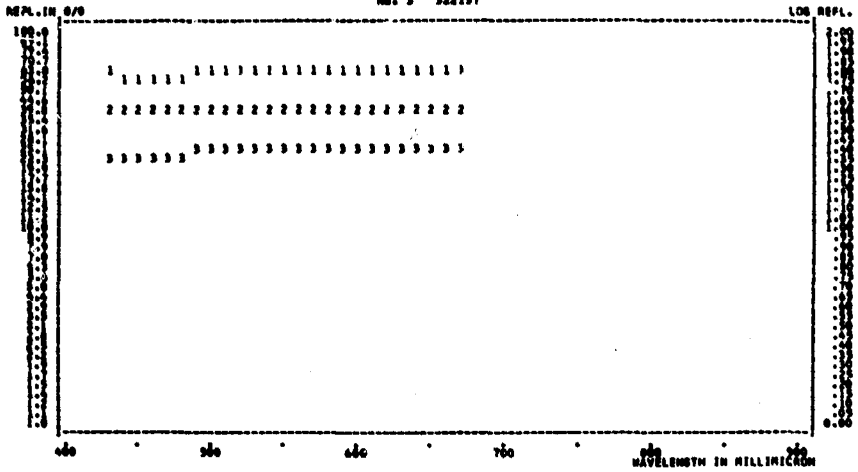
DIAGRAM 85
NO.1 MUSCOVITE FRACTION * SMALLER THAN 0.1 MM / L, I 1 /
NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.2 ID. FRACTION * 0.25 TO 0.5 MM
NO.3 ID. FRACTION * 1 TO 3 MM

DIAGRAM 86
NO.1 GARNET FRACTION * SMALLER THAN 0.1 MM / L, I 1 /
NORTHERN KAZAKHSTAN / BELOIN59ZSJ
NO.2 ID. FRACTION * 0.25 TO 0.5 MM
NO.3 ID. FRACTION * 1 TO 3 MM

DIAGRAM 87
NO.1 EPIDOTE FRACTION * SMALLER THAN 0.1 MM / L, I 1 /
NORTHERN KAZAKHSTAN / BELOIN59ZSJ
NO.2 ID. FRACTION * 0.25 TO 0.5 MM
NO.3 ID. FRACTION * 1 TO 3 MM

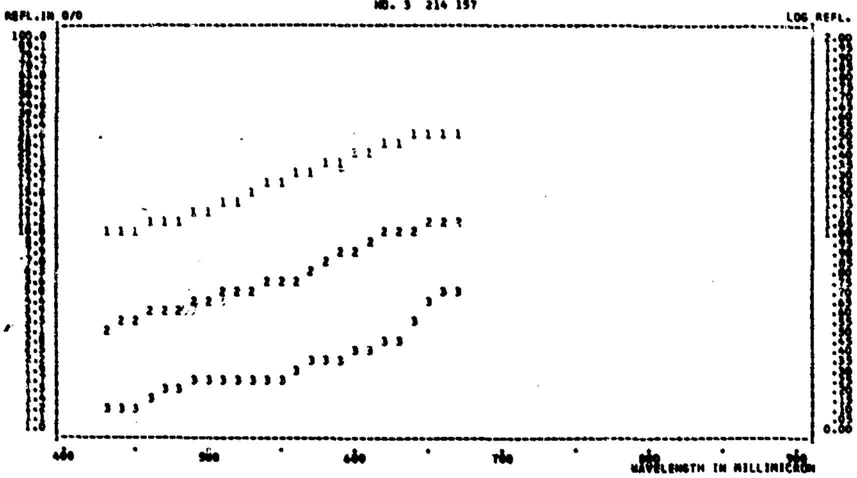
SPECTRAL REFLECTANCE CURVES

DIAGRAM 05



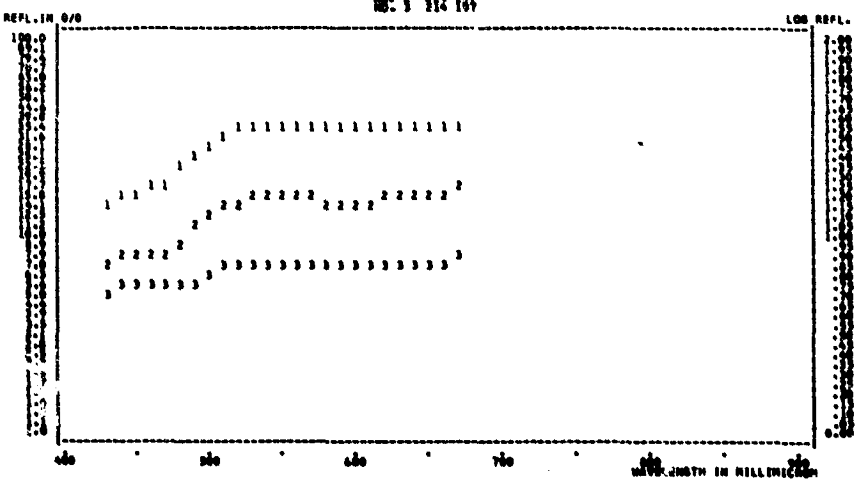
SPECTRAL REFLECTANCE CURVES

DIAGRAM 06



SPECTRAL REFLECTANCE CURVES

DIAGRAM 07



WAVE-LENGTH MMICR.	DIAGRAM 88 NO.1	NO.2	NO.3	DIAGRAM 89 NO.1	NO.2	NO.3	DIAGRAM 90 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	24.9	21.2	18.1	5.6	3.9	2.7	16.5	8.8	5.0
450	24.8	21.0	18.0	5.4	3.9	2.8	19.5	10.4	5.5
470	25.0	21.1	18.1	5.9	4.0	2.8	22.8	13.0	7.2
490	25.4	21.2	18.1	6.3	4.2	2.9	25.0	14.5	8.8
510	26.1	21.6	18.2	6.7	4.5	3.0	27.0	15.8	9.5
530	27.3	22.2	18.8	7.8	5.1	3.5	29.0	16.8	10.3
550	28.3	23.4	20.0	9.1	6.4	4.4	30.0	18.1	11.7
570	29.3	24.2	21.0	11.0	8.1	5.5	31.8	19.6	13.8
590	30.0	24.5	21.5	13.3	10.3	7.4	33.2	21.5	15.2
610	30.2	24.6	21.7	15.5	12.4	9.2	34.3	22.5	16.3
630	30.3	25.0	21.9	17.0	14.0	10.0	34.6	23.0	16.5
650	30.0	25.0	21.7	17.4	14.1	10.0	34.7	22.8	16.8
670	30.0	25.0	21.6	17.5	14.2	10.0	34.9	21.2	16.4
690	.	.	.	.	.	.	.	.	.
710	.	.	.	.	.	.	.	.	.
730	.	.	.	.	.	.	.	.	.
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

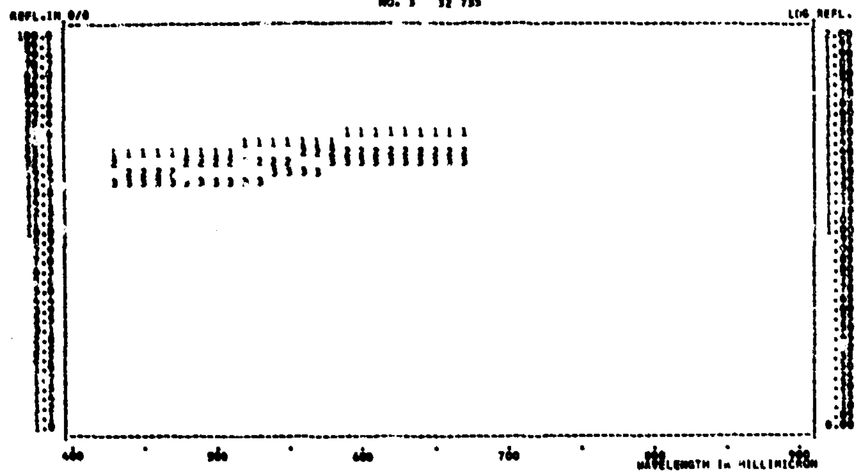
DIAGRAM 88
NO.1 COMMON CHERNOZEM DEVELOPED ON LOESS, MOISTURE CONTENT 0 PERCENT / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.2 ID. MOISTURE CONTENT 10 PERCENT
NO.3 ID. MOISTURE CONTENT 20 PERCENT

DIAGRAM 89
NO.1 CHESTNUT SOIL DEVELOPED ON RED WEATHERING CRUST, MOISTURE CONTENT 0 PERCENT / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.2 ID. MOISTURE CONTENT 10 PERCENT
NO.3 ID. MOISTURE CONTENT 20 PERCENT

DIAGRAM 90
NO.1 TAKYR SOIL MOISTURE CONTENT 2.8 PERCENT / L, I (1) / 1951 TO 1954 / WEST TURKMENIA / BELOIN58NFI
NO.2 ID. MOISTURE CONTENT 30 PERCENT
NO.3 ID. MOISTURE CONTENT 11.7 PERCENT

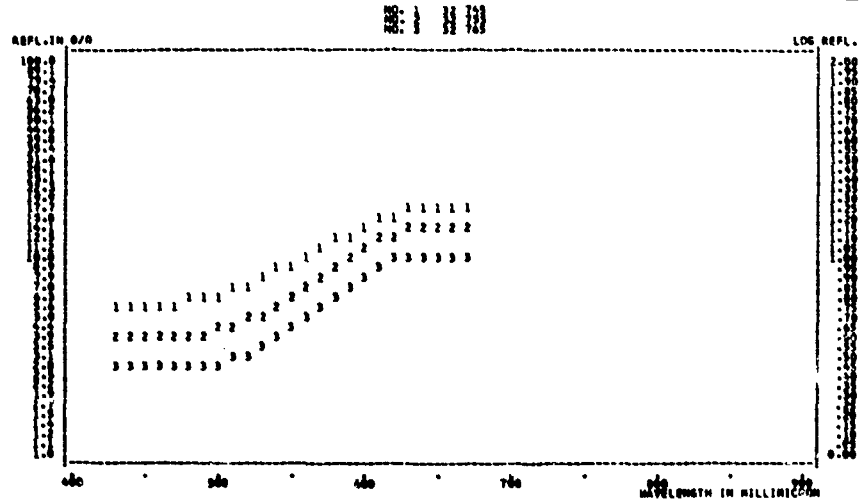
SPECTRAL REFLECTANCE CURVES

DIAGRAM 9a



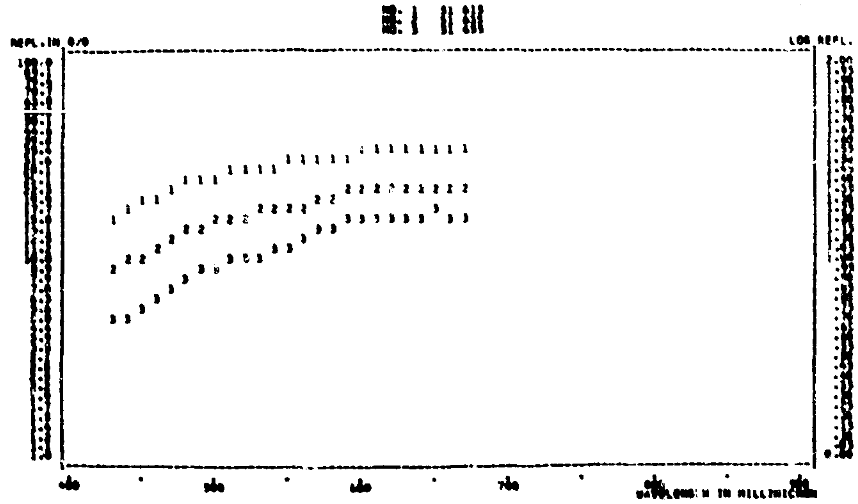
SPECTRAL REFLECTANCE CURVES

DIAGRAM 9b



SPECTRAL REFLECTANCE CURVES

DIAGRAM 9c



WAVE-LENGTH MMICR.	DIAGRAM 91 NO.1	DIAGRAM 91 NO.2	DIAGRAM 91 NO.3	DIAGRAM 92 NO.1	DIAGRAM 92 NO.2	DIAGRAM 92 NO.3	DIAGRAM 93 NO.1	DIAGRAM 93 NO.2	DIAGRAM 93 NO.3
400	.	.	.	.	.	.	.	.	.
430	25.8	18.5	9.8	7.0	6.5	3.5	.	.	.
450	22.2	16.0	8.7	6.5	6.0	3.3	.	.	.
470	20.0	14.9	8.5	6.2	6.0	3.0	.	.	.
490	21.2	16.5	9.2	7.0	7.0	3.0	.	.	.
510	22.2	17.8	10.0	7.5	7.5	3.4	.	.	.
530	23.3	19.0	11.2	8.3	8.0	4.0	.	.	.
550	26.0	20.5	13.0	9.8	9.5	4.9	14.0	27.2	8.2
570	29.5	22.0	15.0	11.0	11.0	6.0	14.7	27.0	9.0
590	31.5	23.0	16.0	12.2	11.6	6.5	15.2	27.0	10.7
610	33.5	24.0	16.8	13.0	12.4	7.3	15.6	26.8	10.8
630	35.3	25.2	17.8	13.8	13.0	7.8	16.6	30.0	13.2
650	37.3	26.2	18.5	14.8	14.0	8.5	18.8	32.0	15.0
670	40.3	29.0	20.6	16.2	15.0	9.5	20.0	33.2	15.7
690	45.0	34.5	28.7	19.0	17.0	10.8	21.0	34.5	17.4
710	49.5	39.5	30.5	21.7	18.5	12.2	24.0	37.0	20.2
730	54.0	45.0	45.0	24.5	21.0	13.5	39.0	49.5	22.4
750	.	.	.	.	.	.	.	52.7	23.[illegible]
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

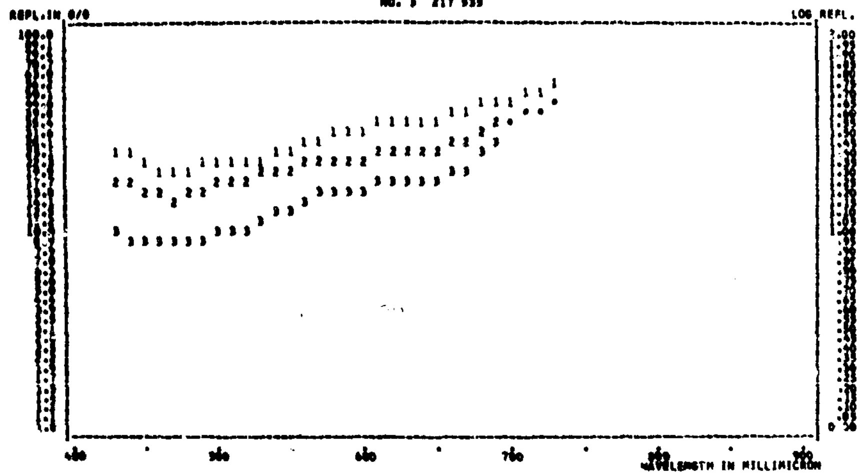
DIAGRAM 91
NO.1 LIGHT-GRAY FOREST SOIL HEAVILY PODZOLIZED, AIR-DRY / L, I 1 / ANDRVL58SPL
NO.2 LIGHT-GRAY FOREST SOIL DEEP, HEAVILY PODZOLIZED, MOISTURE CONTENT 2.95 PERCENT / L, I 1 / ANDRVL58SPL
NO.3 ID. MOISTURE CONTENT 10.0 PERCENT

DIAGRAM 92
NO.1 CHERNOZEM PODZOLIZED, AIR-DRY / L, I 1 / ANDRVL58SPL
NO.2 ID. MOISTURE CONTENT 1.7 PERCENT
NO.3 ID. MOISTURE CONTENT 19.7 PERCENT

DIAGRAM 93
NO.1 FALLOW FIELD BARE SOIL (GRAY LOAM), MOIST, AFTER HARROWING / P, I 3 / JULY 8, 1957, SA 35 / TOMSK / BELOSV59AFL
NO.2 ID. DRY / AUGUST 5, 1957, SA 50
NO.3 ID. TWO HOURS AFTER RAINFALL / AUGUST 25, 1957, SA 36

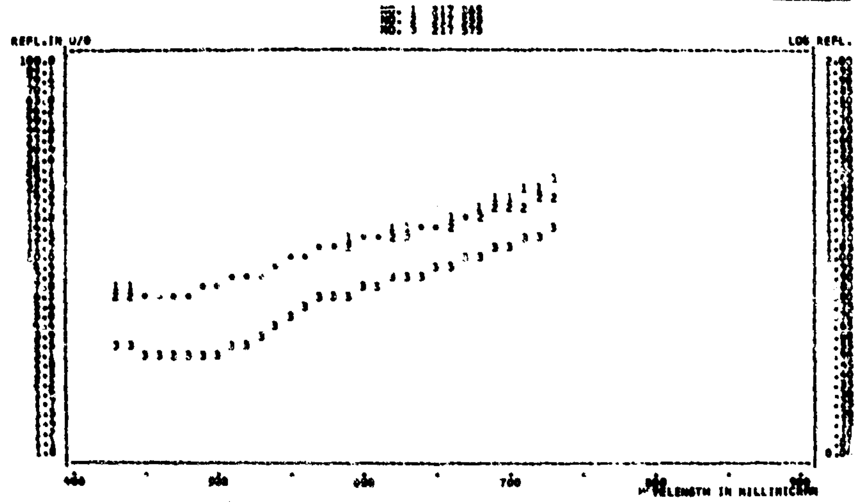
SPECTRAL REFLECTANCE CURVES

DIAGRAM 91



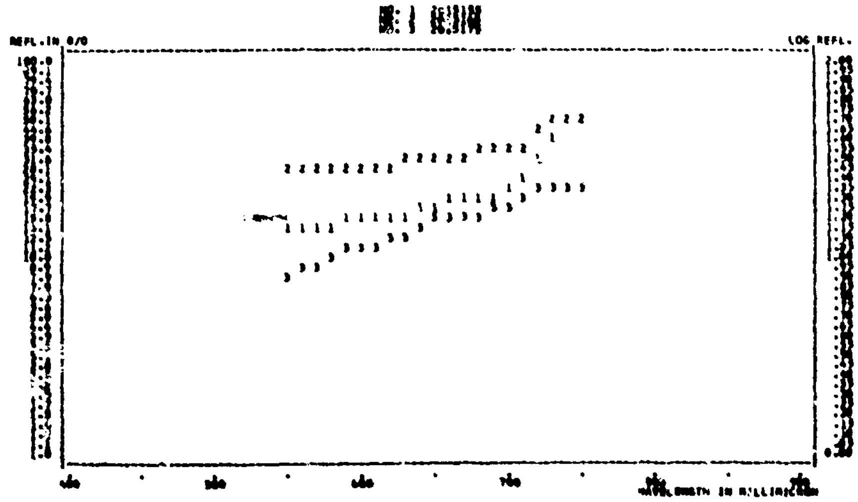
SPECTRAL REFLECTANCE CURVES

DIAGRAM 92



SPECTRAL REFLECTANCE CURVES

DIAGRAM 93



WAVE-LENGTH MMICR.	DIAGRAM 94 NO.1	NO.2	NO.3	DIAGRAM 95 NO.1	NO.2	NO.3	DIAGRAM 96 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	.	.	.	.	.	.	.	.	.
450	8.4	4.5	4.5	15.7	16.0	15.5	5.8	6.0	4.4
470	8.7	4.9	4.0	16.5	16.0	16.0	5.7	6.0	4.5
490	9.4	5.4	4.0	17.7	16.1	17.0	5.9	5.9	4.4
510	9.8	6.4	4.7	18.8	16.5	17.8	7.0	6.5	4.7
530	10.5	8.0	5.4	20.2	17.5	18.5	7.7	6.5	5.0
550	10.8	9.3	5.8	21.3	18.2	19.1	8.4	6.7	5.3
570	11.7	10.7	6.3	21.9	18.5	19.7	8.7	6.9	5.6
590	13.4	11.7	7.0	22.7	18.8	20.3	9.0	7.4	6.6
610	15.1	12.7	7.8	24.6	20.0	20.5	9.2	7.5	6.8
630	16.4	13.1	7.8	26.4	21.2	20.7	9.5	7.5	7.5
650	17.4	13.5	7.8	27.2	21.2	21.2	10.2	7.6	7.8
670	18.2	14.3	8.3	27.0	20.5	21.5	10.8	7.7	7.5
690	18.9	14.7	8.9	27.6	20.1	21.7	11.8	8.0	7.3
710	19.5	15.4	9.7	28.4	19.9	21.4	13.0	7.7	7.6
730	20.0	15.8	10.1	29.7	20.6	22.0	14.3	7.3	7.8
750	20.5	16.4	10.4	30.7	21.7	22.7	15.5	6.7	8.0
770	21.0	17.0	10.6	31.5	21.3	22.9	16.2	6.5	8.1
790	21.5	17.8	10.8	32.2	21.2	23.0	16.8	7.2	8.0
810	22.0	18.4	11.1	32.8	21.6	23.4	17.4	7.7	8.3
830	22.5	18.8	12.0	33.4	21.7	23.6	18.0	8.3	8.8
850	23.0	19.4	12.8	34.2	22.5	24.9	18.7	8.6	9.2
870	23.3	19.6	13.4	34.9	24.2	25.5	19.0	8.9	9.5
890	23.6	19.7	13.7	35.5	25.5	24.6	19.0	10.1	9.8

DIAGRAM 94

NO.1 LOAMY SOIL DRY, GRAY / G, I 2,(1) / SEPTEMBER 8, 1958, SA 46 / ALEKVA60SDP

NO.2 LOAM MOIST, BROWN-YELLOW / G, I 2,(1) / SEPTEMBER 15, 1958, SA 42 / ALEKVA60SDP

NO.3 SLIMY-GLEY SOIL MOIST, BLACK / G, I 2,(1) / JULY 17, 1958, SA 60 / ALEKVA60SDP

DIAGRAM 95

NO.1 DIRT ROAD DRY (YELLOWISH-GRAY SAND) / G, I 2,(1) / JULY 17, 1958, SA 58 TO 60 / ALEKVA60SDP

NO.2 ROAD STONE PAVEMENT, DRY / G, I 2,(1) / JULY 17, 1958, SA 58 TO 60 / ALEKVA60SDP

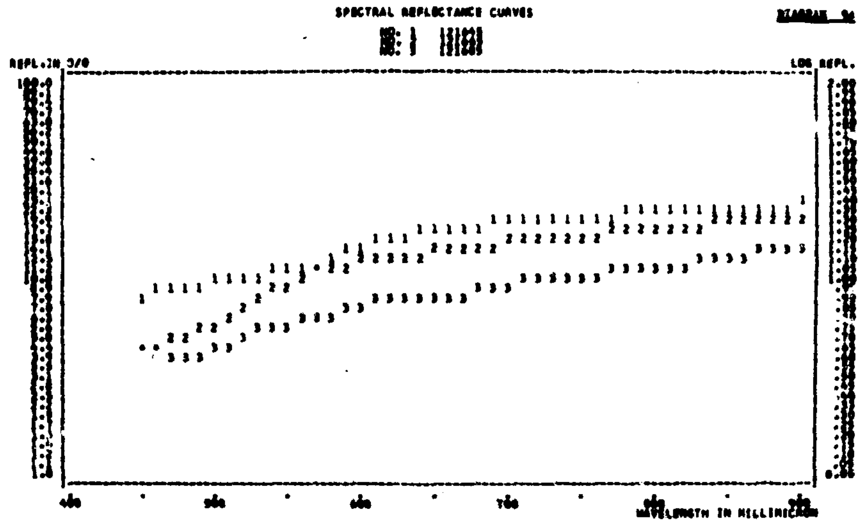
NO.3 ROAD ASPHALT PAVEMENT, DRY / G, I 2,(1) / JULY 17, 1958, SA 58 TO 60 / ALEKVA60SDP

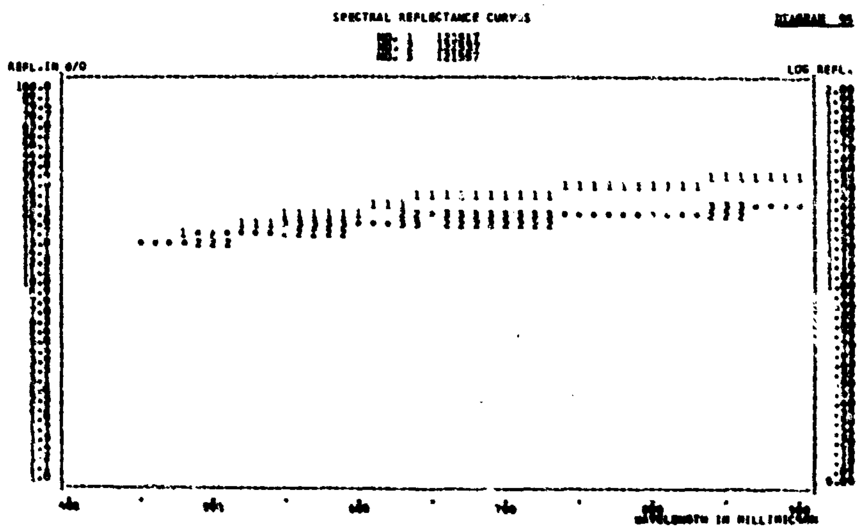
DIAGRAM 96

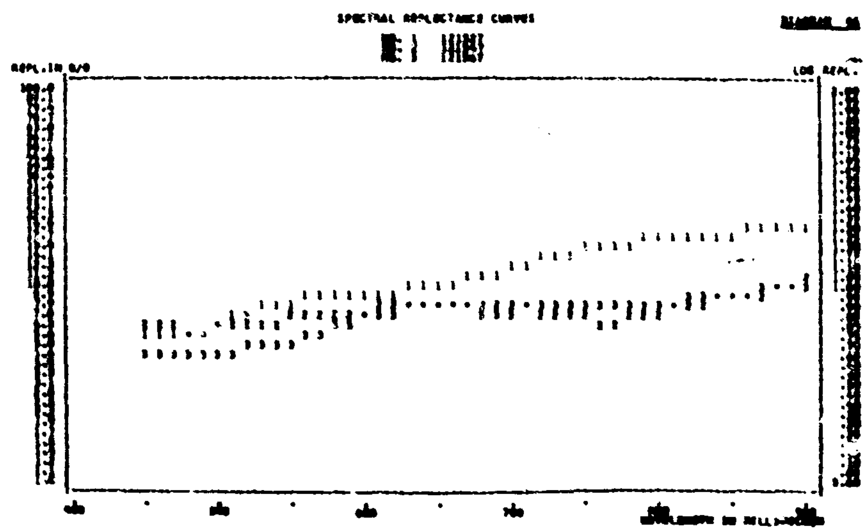
NO.1 DIRT ROAD WET (YELLOWISH-GRAY SAND) / G, I 2,(1) / JULY 17, 1958, SA 58 TO 60 / ALEKVA60SDP

NO.2 ROAD STONE PAVEMENT, WET / G, I 2,(1) / JULY 17, 1958, SA 58 TO 60 / ALEKVA60SDP

NO.3 ROAD ASPHALT PAVEMENT, WET / G, I 2,(1) / JULY 17, 1958, SA 58 TO 60 / ALEKVA60SDP


SPECTRAL REFLECTANCE CURVES
REFL.IN 0/0
LOG REFL.
400
500
600
700


SPECTRAL REFLECTANCE CURV:S
REFL.IN 0/0
LOG REFL.
400
600
700


SPECTRAL REFLECTANCE CURVES
REFL.IN 0/0
LOG REFL.
600
700

WAVE-LENGTH MMICR.	DIAGRAM 97 NO.1	DIAGRAM 97 NO.2	DIAGRAM 97 NO.3	DIAGRAM 98 NO.1	DIAGRAM 98 NO.2	DIAGRAM 98 NO.3	DIAGRAM 99 NO.1	DIAGRAM 99 NO.2	DIAGRAM 99 NO.3
400	.	.	.	.	.	.	.	.	.
430	.	.	.	9.0	26.4	17.1	.	.	.
450	15.6	6.3	5.6	9.3	27.0	19.3	.	.	.
470	16.2	7.0	5.4	9.8	29.0	22.5	.	.	.
490	17.0	7.5	6.0	10.1	31.0	26.0	.	.	.
510	18.2	8.5	6.7	10.9	32.1	28.6	.	.	.
530	19.7	9.5	7.5	12.5	33.8	31.5	.	.	.
550	21.2	10.8	8.2	15.0	34.8	34.8	24.5	21.5	20.8
570	22.6	12.0	9.0	17.5	35.5	37.2	27.1	23.2	22.5
590	23.8	13.3	9.8	19.5	36.4	38.3	29.5	25.3	24.8
610	25.2	14.2	10.5	20.4	37.0	39.2	31.3	27.0	26.2
630	25.9	14.6	10.8	21.8	37.6	39.5	32.0	27.3	26.4
650	26.7	14.9	11.4	21.6	37.2	39.5	33.2	28.0	27.2
670	27.6	15.4	12.0	21.6	38.0	39.5	34.0	31.2	30.0
690	28.2	16.5	12.5	.	.	.	36.0	31.8	31.0
710	28.9	17.0	13.1	.	.	.	41.3	33.0	31.7
730	29.2	18.5	13.6	.	.	.	41.7	33.5	32.5
750	29.5	19.2	14.3	.	.	.	41.8	33.7	32.7
770	30.0	19.7	15.0	.	.	.	.	.	.
790	30.5	20.3	15.7	.	.	.	.	.	.
810	31.1	20.8	16.5	.	.	.	.	.	.
830	31.9	21.4	17.3	.	.	.	.	.	.
850	32.8	22.0	17.9	.	.	.	.	.	.
870	33.1	22.3	18.1	.	.	.	.	.	.
890	33.4	22.5	18.1	.	.	.	.	.	.

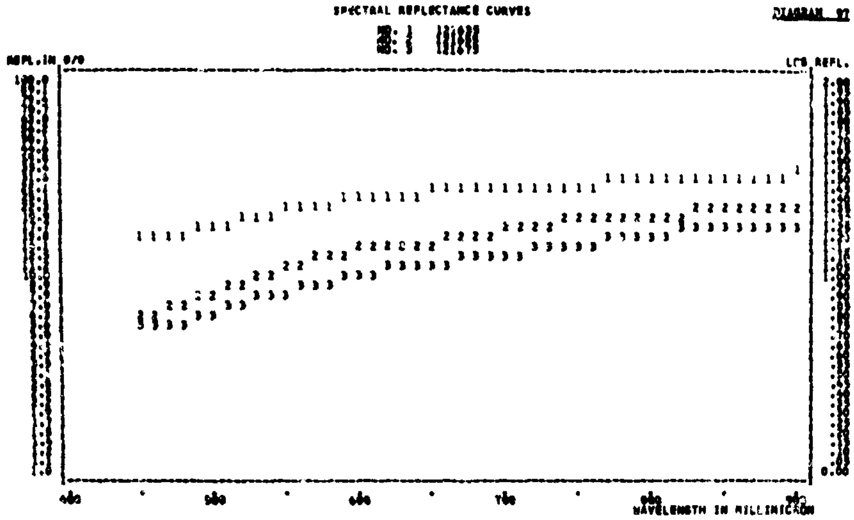
DIAGRAM 97
NO.1 LOAMY SAND SOIL DRY, LIGHT GRAY / G, I 2,(1) / AUGUST 11, 1958, SA 56 / ALEKVA60SDP
NO.2 ID. WITH A BROWNISH TINT / SA 53
NO.3 ID. FRESH, BROWN-GRAY / SA 47

DIAGRAM 98
NO.1 CLAY GRAY-BROWN, PARENT MATERIAL / L, I (1) / 1951 TO 1954 / WEST TURKMENIA / BELOIN58NFI (AFTER LJALIKOV ET AL., 1955)
NO.2 ID. GREEN-GRAY
NO.3 ID. BROWN-YELLOW

DIAGRAM 99
NO.1 RIVER SAND DRY, LIGHT BROWNISH-GRAY, WITH SMOOTH SURFACE / G, I 1,3 / 1957, SA 45 / TOMSK / BELOSV59AFL
NO.2 ID. WITH SMALL ARTIFICIAL FURROWS (10 MM DEEP, 30 MM APART), PARALLEL TO SHADOW DIRECTION
NO.3 ID. WITH SMALL ARTIFICIAL FURROWS (10 MM DEEP, 30 MM APART), PERPENDICULAR TO SHADOW DIRECTION

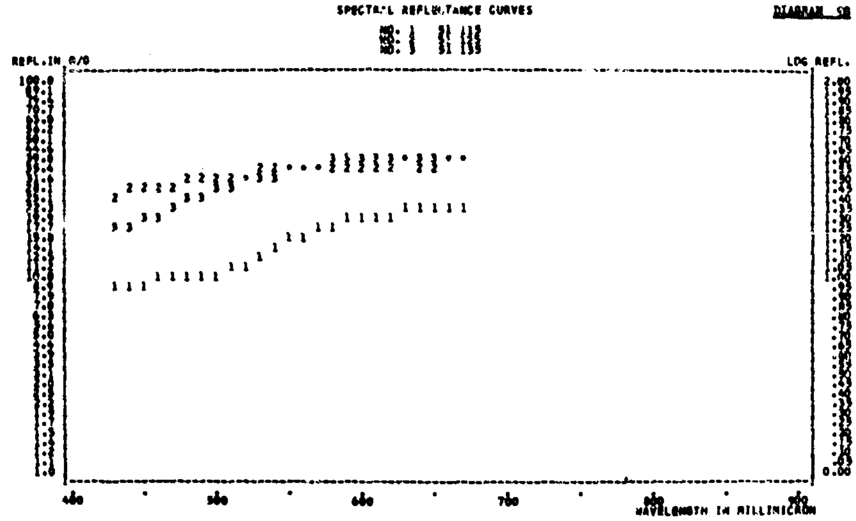
SPECTRAL REFLECTANCE CURVES

DIAGRAM 97



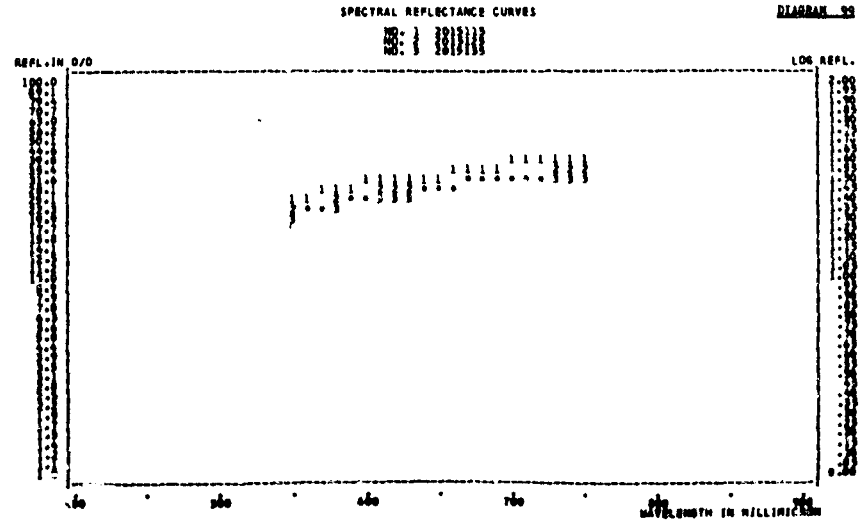
SPECTRAL REFLECTANCE CURVES

DIAGRAM 98



SPECTRAL REFLECTANCE CURVES

DIAGRAM 99



WAVE-LENGTH MMICR.	DIAGRAM 100 NO.1	NO.2	NO.3	DIAGRAM 101 NO.1	NO.2	NO.3	DIAGRAM 102 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	9.0	5.2	22.0	19.0	9.1	.	7.0	80.8	33.2
450	8.6	5.0	23.5	20.0	8.6	.	7.2	80.2	34.5
470	8.2	5.0	26.2	22.1	8.5	.	8.3	80.0	37.2
490	7.6	5.3	28.6	24.3	8.6	.	9.0	80.0	40.0
510	7.8	6.0	31.4	27.0	8.7	.	10.1	79.9	42.6
530	8.1	6.3	33.8	29.1	9.5	.	12.1	79.7	46.0
550	9.8	6.8	36.0	30.9	10.0	.	13.6	79.8	50.9
570	13.2	6.8	38.0	33.0	11.7	.	15.0	79.8	56.2
590	16.9	6.3	39.6	34.2	12.9	.	16.0	79.8	58.9
610	19.3	5.1	41.0	35.3	13.9	.	16.4	79.8	60.0
630	20.4	4.1	41.7	35.2	14.0	.	16.4	79.7	60.2
650	20.6	3.8	41.4	34.8	13.9	.	16.5	79.8	59.8
670	20.0	3.7	40.4	32.3	13.1	.	16.2	79.8	59.2
690	.	.	.	.	.	.	.	.	.
710	.	.	.	.	.	.	.	.	.
730	.	.	.	.	.	.	.	.	.
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

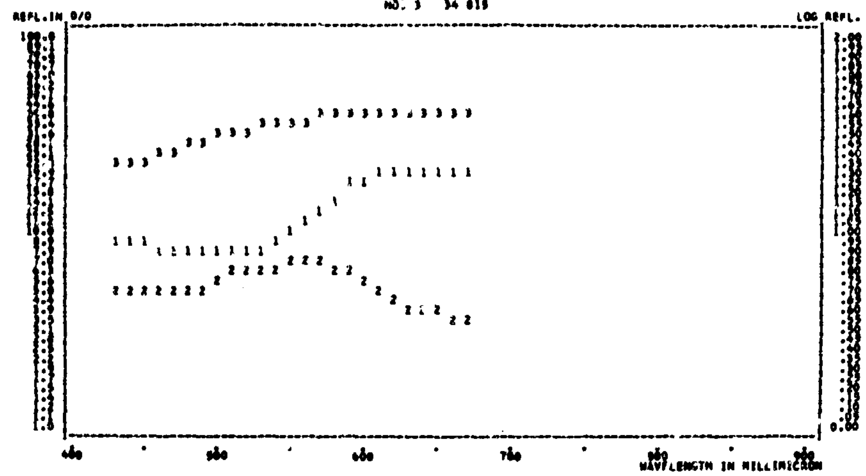
DIAGRAM 100
NO.1 SALT LAKE LIGHT PURPLE / G, I 1 / (SUMMER) 1954 / SW TURKMENIA, MOLLA KORA REGION / LJALKS60IOP
NO.2 ID. GREEN
NO.3 TAKYR G, I 1 / (SUMMER) 1954 / SW TURKMENIA, BOE-DAG REGION / LJALKS60IOP

DIAGRAM 101
NO.1 CLAY DARK-GRAY, COVERED WITH A THIN SALT CRUST / G, I 1 / SW TURKMENIA / LJALKS60IOP
NO.2 ID. DARK-GRAY, SALT CRUST SCRATCHED OFF

DIAGRAM 102
NO.1 DARK AREA OF THE KEL,-KOR SHOR (SALT LAKE) / G, I 1 / (SUMMER) 1954 / SW TURKMENIA / LJALKS60IOP
NO.2 AREA COVERED BY A FRESH AND MOIST SALT CRUST (KEL,-KOR SHOR) / G, I 1 / (SUMMER) 1954 / SW TURKMENIA / LJALKS60IOP
NO.3 SALT CRUST SOILED BY SAND AND DUST, BED OF THE AKTAM RIVER / G, I 1 / (SUMMER) 1954 / SW TURKMENIA / LJALKS60IOP

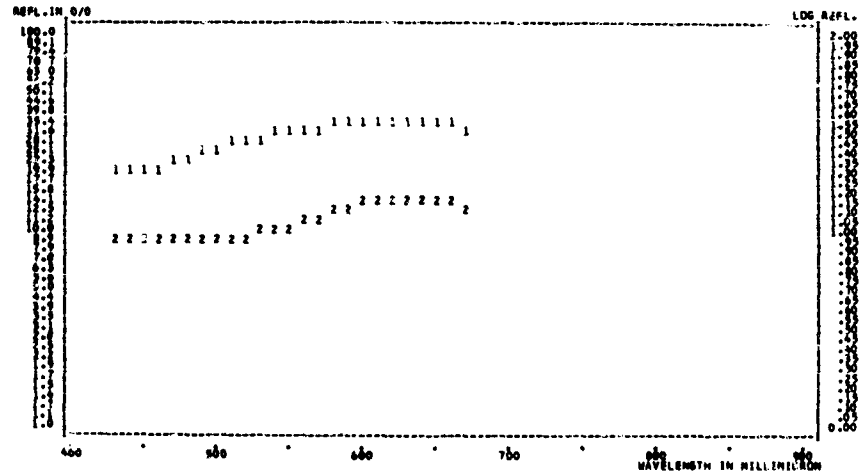
SPECTRAL REFLECTANCE CURVES

DIAGRAM 100



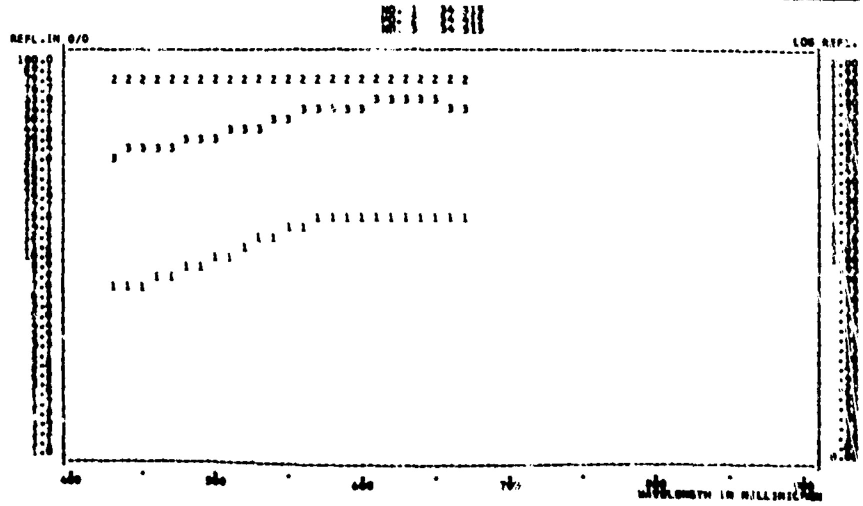
SPECTRAL REFLECTANCE CURVES

DIAGRAM 101



SPECTRAL REFLECTANCE CURVES

DIAGRAM 102



WAVE-LENGTH MMICR.	DIAGRAM 103 NO.1	NO.2	NO.3	DIAGRAM 104 NO.1	NO.2	NO.3	DIAGRAM 105 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	19.0	26.0	1.7	8.7	7.2	.	44.5	19.1	.
450	20.0	29.3	2.0	9.5	7.2	.	47.4	20.6	.
470	22.4	30.8	2.3	10.4	7.7	.	50.0	21.8	.
490	25.6	35.0	2.6	12.0	7.9	.	53.7	23.5	.
510	30.0	37.4	2.9	13.0	8.2	.	56.7	24.9	.
530	34.0	39.1	3.5	14.3	8.7	.	60.1	26.1	.
550	39.5	41.3	4.0	16.3	9.0	.	63.1	27.5	.
570	45.0	42.2	6.7	18.3	9.3	.	65.8	28.5	.
590	49.5	41.8	9.3	19.8	9.6	.	68.0	29.3	.
610	52.1	40.0	10.7	21.3	10.0	.	69.0	29.2	.
630	54.0	37.8	12.0	22.0	10.2	.	68.6	28.6	.
650	54.8	36.0	12.2	22.0	10.8	.	67.8	27.9	.
670	54.9	34.0	12.0	21.5	10.0	.	66.2	.	.
690	.	.	.	.	.	.	.	.	.
710	.	.	.	.	.	.	.	.	.
730	.	.	.	.	.	.	.	.	.
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

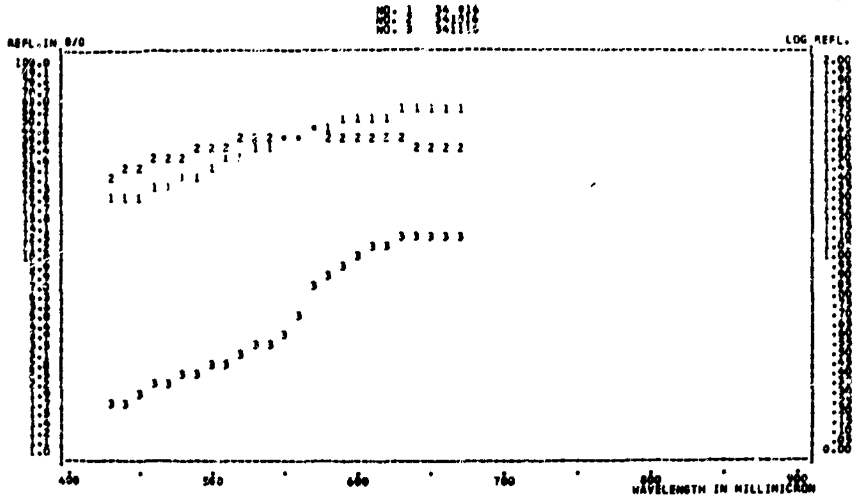
DIAGRAM 103
NO.1 UPPER CARBONATE CRETASSIC BROWN, FRESHLY BROKEN / G, I 1 / SW TURKMENIA, SMALL BALKHAN / LJALKS60IOP
NO.2 ID. GREEN
NO.3 LIMONITE FRESHLY DEPOSITED ON THE BOTTOM OF CREEKS / G, I 1 / SW TURKMENIA, BOE-DAG REGION / LJALKS60IOP

DIAGRAM 104
NO.1 VOLCANIC ROCK FRESHLY BROKEN, YELLOW-GRAY COLOR / G, I 1 / SW TURKMENIA / LJALKS60IOP
NO.2 ID. COVERED WITH DESERT VARNISH, BLACK COLOR

DIAGRAM 105
NO.1 UPPER CARBONATE CRETASSIC WEATHERED / G, I 1 / SW TURKMENIA / LJALKS60IOP
NO.2 ID. GREEN, UNWEATHERED

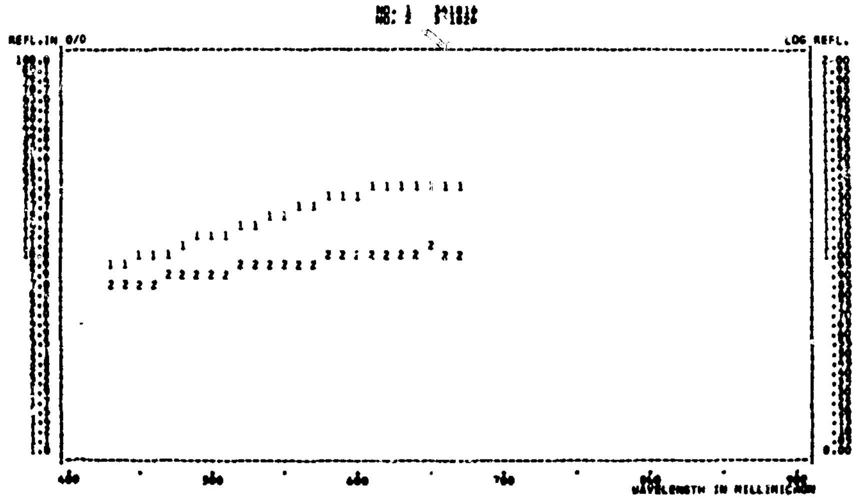
SPECTRAL REFLECTANCE CURVES

DIAGRAM 1a3



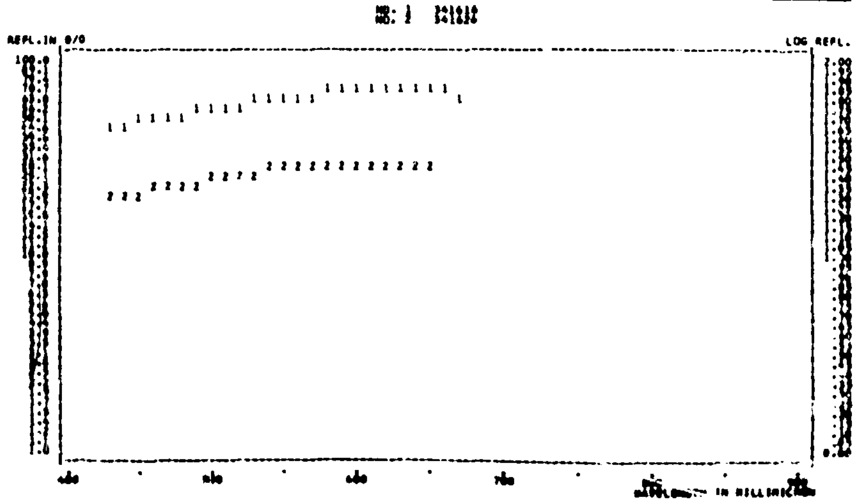
SPECTRAL REFLECTANCE CURVES

DIAGRAM 1a4



SPECTRAL REFLECTANCE CURVES

DIAGRAM 1a5



WAVE-LENGTH MMICR.	DIAGRAM 106 NO.1	DIAGRAM 106 NO.2	DIAGRAM 106 NO.3	DIAGRAM 107 NO.1	DIAGRAM 107 NO.2	DIAGRAM 107 NO.3	DIAGRAM 108 NO.1	DIAGRAM 108 NO.2	DIAGRAM 108 NO.3
400	.	.	.	.	.	.	.	.	.
430	26.6	9.0	.	.	.	.	.	.	.
450	30.0	9.4	.	.	.	.	.	.	.
470	33.4	10.9	.	.	.	.	.	.	.
490	36.5	12.3	.	57.5	36.0	30.0	10.0	7.4	.
510	40.0	14.9	.	61.7	37.0	30.0	10.2	7.0	.
530	43.8	17.3	.	68.5	38.0	30.5	12.2	8.4	.
550	47.1	19.5	.	73.5	39.5	32.0	14.0	10.0	.
570	50.6	21.7	.	76.5	41.7	34.5	14.3	10.0	.
590	53.7	23.0	.	80.2	45.0	38.0	14.5	9.5	.
610	55.4	24.0	.	87.0	46.0	39.5	14.0	8.0	.
630	56.5	24.2	.	93.0	47.5	40.0	13.0	7.0	.
650	57.1	24.6	.	96.2	49.0	40.2	12.0	6.6	.
670	55.4	24.6	.	97.0	51.5	41.0	11.0	7.0	.
690	.	.	.	96.5	55.5	43.0	10.2	8.0	.
710	.	.	.	95.0	60.5	45.5	10.0	10.8	.
730	.	.	.	92.8	65.0	48.5	10.7	15.3	.
750	.	.	.	91.5	68.2	51.2	15.0	21.3	.
770	.	.	.	91.5	69.5	53.5	28.0	28.0	.
790	.	.	.	90.5	69.0	55.5	43.2	32.5	.
810	.	.	.	86.5	67.0	55.5	52.2	37.0	.
830	.	.	.	80.0	65.5	54.5	56.0	39.0	.
850	.	.	.	74.5	64.5	54.0	57.5	40.5	.
870	.	.	.	71.5	65.0	54.0	55.2	41.0	.
890	.	.	.	68.5	65.8	53.8	49.5	41.0	.

DIAGRAM 106
NO.1 ROCK YELLOW-GRAY / G, I 1 / SW TURKMENIA / LJALKS60IOP
NO.2 ID. COVERED BY LICHENS OF BROWN-YELLOW COLOR

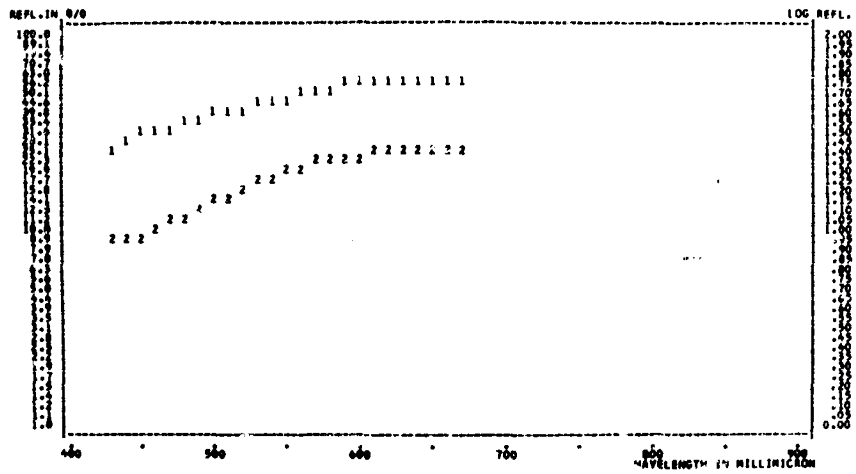
DIAGRAM 107
NO.1 SOLONCHAK P, I 7 / JULY, 1958 TO 1960 / ASHKHABAD / ARCYES62ISJ
NO.2 TAKYR P, I 7 / JULY, 1958 TO 1960 / ASHKHABAD / ARCYES62ISJ
NO.3 STABLE SAND P, I 7 / JULY, 1958 TO 1960 / ASHKHABAD / ARCYES62ISJ

DIAGRAM 108
NO.1 WHITE SAXAUL GRAY-GREEN SHOOTS / P, I 7 / JULY, 1958 TO 1960 / ASHKHABAD / ARCYES62ISJ
NO.2 SHALLOW DEPRESSIONS P, I 7 / JULY, 1958 TO 1960 / ASHKHABAD / ARCYES62ISJ

SPECTRAL REFLECTANCE CURVES

DIAGRAM 1.6

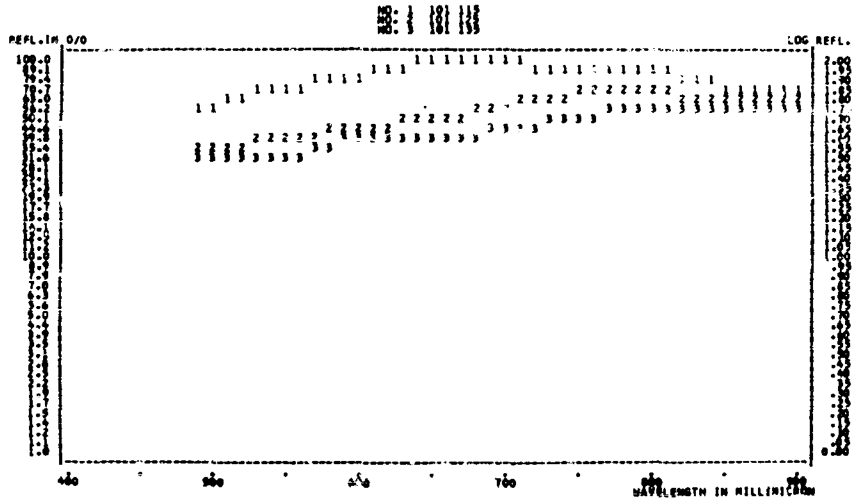
NO. 1 [illegible]
NO. 2 [illegible]



SPECTRAL REFLECTANCE CURVES

DIAGRAM 1.7

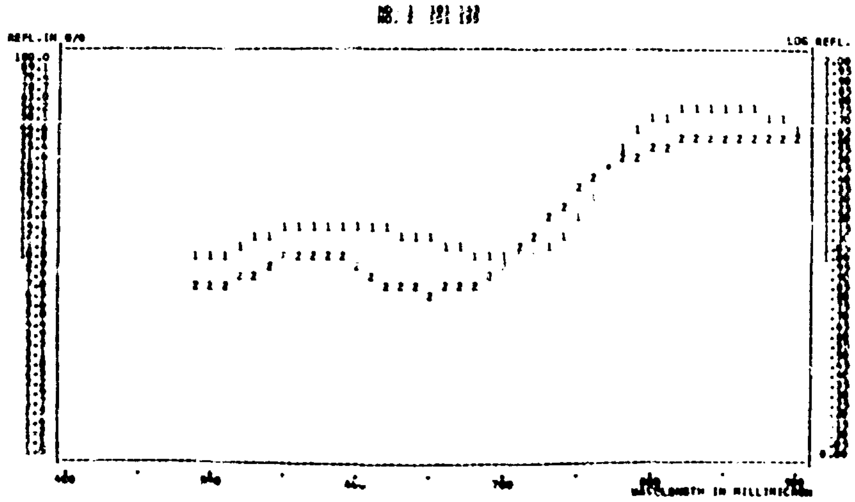
NO. 1 101 [illegible]
NO. 2 101 [illegible]
NO. 3 101 [illegible]



SPECTRAL REFLECTANCE CURVES

DIAGRAM 1.8

NO. 1 [illegible]
NO. 2 [illegible]



WAVE-LENGTH MMICR.	DIAGRAM 109 NO.1	NO.2	NO.3	DIAGRAM 110 NO.1	NO.2	NO.3	DIAGRAM 111 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	6.7	4.4	15.2	17.7	6.4	20.0	17.0	20.0	.
450	7.1	4.3	15.4	19.0	6.8	20.0	20.0	21.0	.
470	7.4	4.0	18.2	20.5	7.8	21.3	23.0	22.5	.
490	8.0	4.4	20.2	22.2	8.8	23.0	25.5	23.6	.
510	8.5	4.5	22.0	24.1	9.3	24.9	27.2	24.6	.
530	9.0	4.7	22.8	26.1	10.3	26.2	28.6	25.0	.
550	9.4	4.8	23.8	28.4	11.2	27.4	30.0	26.0	.
570	10.0	5.0	25.0	30.6	12.2	28.8	31.8	28.4	.
590	10.7	5.1	27.0	31.[illegible]	13.5	29.6	33.[illegible]	30.3	.
610	11.0	5.0	28.0	31.8	14.3	30.1	34.0	30.8	.
630	11.5	5.3	28.5	31.5	14.3	30.2	33.9	32.0	.
650	11.6	5.6	28.8	31.4	13.3	30.2	33.9	31.6	.
670	11.7	5.7	28.4	31.2	12.9	29.8	33.8	30.0	.
690	.	.	.	.	.	.	.	.	.
710	.	.	.	.	.	.	.	.	.
730	.	.	.	.	.	.	.	.	.
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

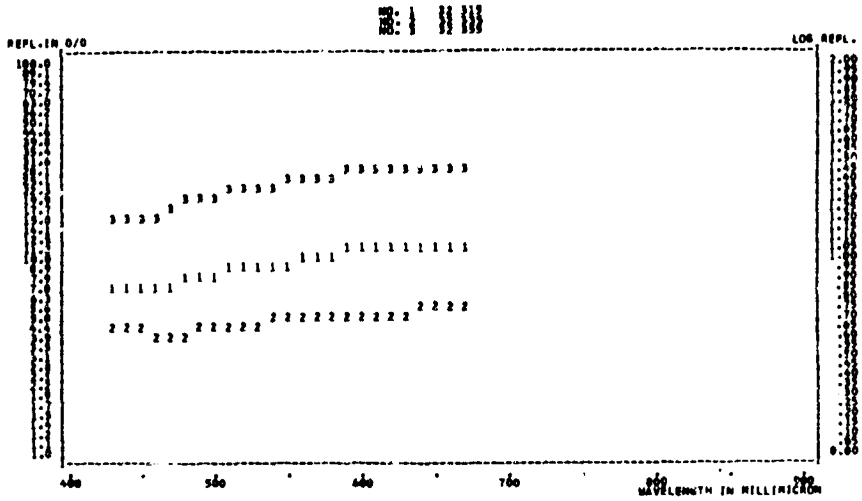
DIAGRAM 109
NO.1 COMMON CHERNOZEM SAMPLE 136A / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.2 MEADOW CHERNOZEMIC SOIL SAMPLE 67 / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.3 CARBONATE CHERNOZEM LOW HUMUS CONTENT, SAMPLE 144 / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT

DIAGRAM 110
NO.1 SHALLOW SOLONETZ SAMPLE 141 / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.2 CHERNOZEM HEAVILY SOLONIZED, SAMPLE 142 / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT
NO.3 GLEY SOLOTH SAMPLE 145 / L, I 1 / NORTHERN KAZAKHSTAN / TOLCJS60PFT

DIAGRAM 111
NO.1 TAKYR SOIL CLAY MATERIAL, DEVELOPED ON COLLUVIUM SAMPLE 1 / L, I (1) / 1951 TO 1954 / WEST TURKMENIA / BELOIN58NFI
NO.2 ID. SAMPLE 180

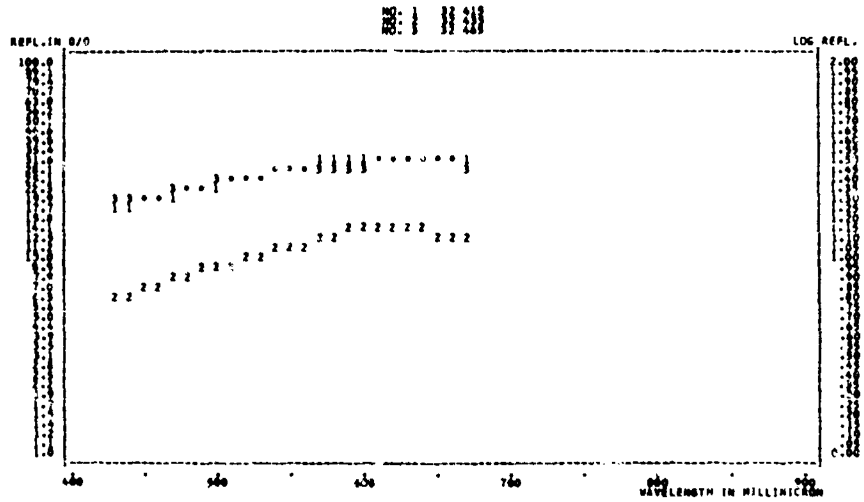
SPECTRAL REFLECTANCE CURVES

DIAGRAM 109



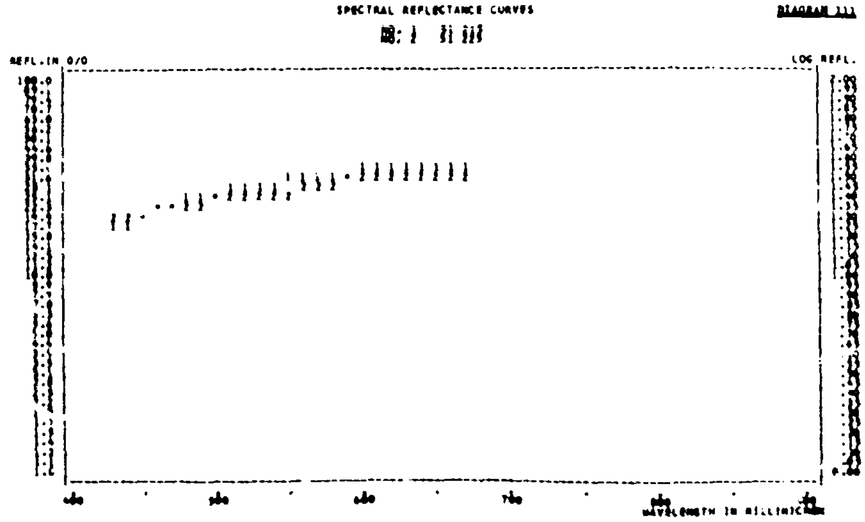
SPECTRAL REFLECTANCE CURVES

DIAGRAM 110



SPECTRAL REFLECTANCE CURVES

DIAGRAM 111



WAVE-LENGTH MMICR.	DIAGRAM 112 NO.1	DIAGRAM 112 NO.2	DIAGRAM 112 NO.3	DIAGRAM 113 NO.1	DIAGRAM 113 NO.2	DIAGRAM 113 NO.3	DIAGRAM 114 NO 1	DIAGRAM 114 NO.2	DIAGRAM 114 NO.3
400	.	.	.	.	.	.	.	.	.
430	12.6	18.0	23.5	4.3	12.3	20.2	8.0	6.3	4.0
450	12.7	18.7	24.2	4.5	13.0	20.2	8.0	6.4	4.0
470	12.8	19.2	24.3	5.2	14.0	21.5	8.0	6.5	4.0
490	13.2	19.2	24.7	5.5	14.5	21.1	8.3	6.6	4.1
510	14.6	19.3	25.2	6.2	15.6	21.2	9.0	6.8	4.2
530	15.6	19.5	25.0	7.3	16.7	21.5	10.0	6.8	4.5
550	17.1	20.8	25.0	9.2	17.1	21.9	10.6	7.3	4.6
570	19.6	21.2	25.0	9.7	16.6	22.5	11.0	7.6	4.8
590	21.0	21.5	24.9	10.2	17.1	22.3	11.2	7.8	5.1
610	21.6	22.3	24.9	10.5	17.8	21.9	12.2	8.0	5.3
630	21.5	22.5	25.0	10.7	18.5	21.5	13.4	8.5	5.6
650	21.0	23.6	25.0	11.5	18.8	21.0	14.0	9.0	6.1
670	20.8	24.5	25.0	12.3	19.2	20.7	13.9	8.8	6.2
690	.	.	.	.	.	.	.	.	.
710	.	.	.	.	.	.	.	.	.
730	.	.	.	.	.	.	.	.	.
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	

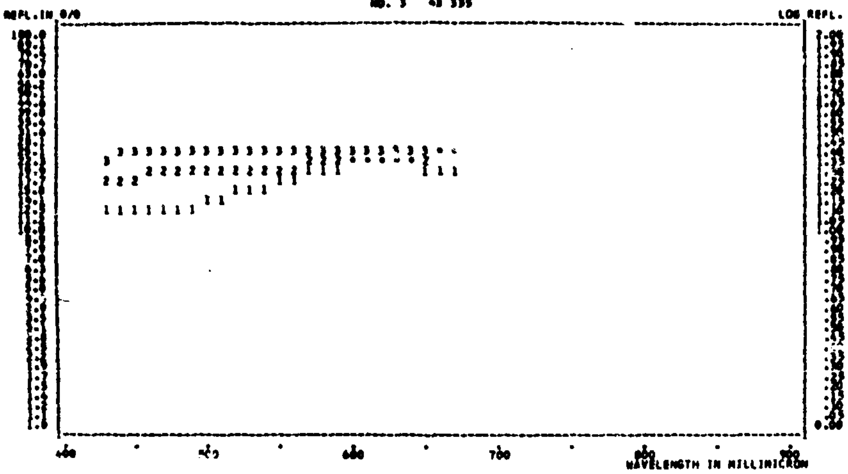
DIAGRAM 112
NO.1 SHALLOW SOLONETZ L, I 1 / TOLCJS590TP
NO.2 GLEY SOLOTH L, I 1 / TOLCJS590TP
NO.3 EXTERNAL SOLONCHAK L, I 1 / TOLCJS590TP

DIAGRAM 113
NO.1 CRYPTOPODZOLIC PEAT SOIL L, I 1 / TOLCJS590TP
NO.2 SODDY PODZOLIC SOIL L, I 1 / TOLCJS590TP
NO.3 GLEY PODZOL L, I 1 / TOLCJS590TP

DIAGRAM 114
NO.1 GRAY FOREST SOIL L, I 1 / TOLCJS590TP
NO.2 COMMON CHERNOZEM L, I 1 / TOLCJS590TP
NO.3 MEADOW SOIL L, I 1 / TOLCJS590TP

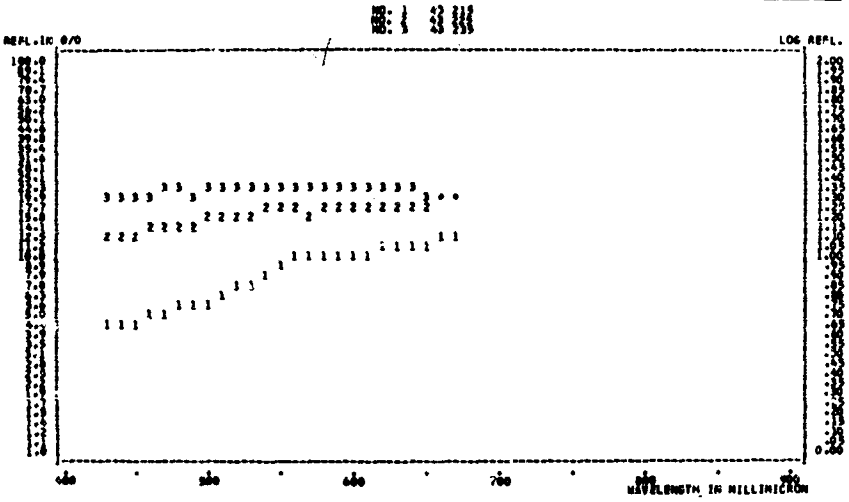
SPECTRAL REFLECTANCE CURVES

DIAGRAM 112



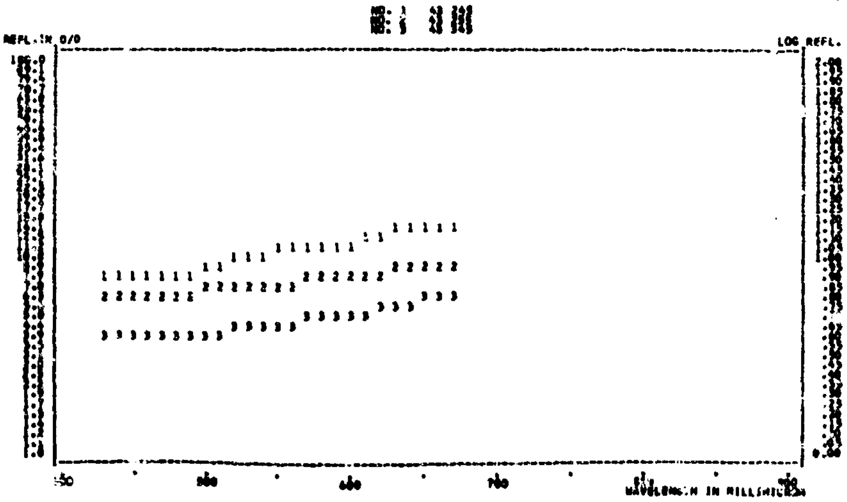
SPECTRAL REFLECTANCE CURVES

DIAGRAM 113



SPECTRAL REFLECTANCE CURVES

DIAGRAM 114



WAVE-LENGTH MMICR.	DIAGRAM 115 NO.1	NO.2	NO.3	DIAGRAM 116 NO.1	NO.2	NO.3	DIAGRAM 117 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	7.5	18.5	8.6	25.8	19.4	11.0	9.7	7.9	7.0
450	8.2	20.0	9.9	22.2	17.9	9.0	8.3	7.2	6.5
470	8.6	22.4	12.6	20.0	17.2	8.0	7.4	6.7	6.2
490	8.8	24.3	14.5	21.2	18.6	9.2	8.4	7.5	7.0
510	9.5	26.9	17.4	22.2	20.2	10.0	9.3	8.2	7.5
530	10.5	29.5	22.7	23.3	21.7	11.0	10.2	9.0	8.3
550	11.7	31.0	28.9	26.0	24.5	13.2	12.0	10.7	9.8
570	13.0	32.4	31.9	29.5	27.5	15.0	13.7	12.0	11.0
590	14.5	33.8	34.1	31.5	29.0	16.5	15.0	13.5	12.2
610	15.0	35.0	37.0	33.5	30.2	18.0	16.2	14.3	13.0
630	15.2	35.5	38.7	35.3	31.5	19.5	17.2	15.0	13.8
650	15.2	36.0	38.4	37.3	33.0	21.2	18.5	16.3	14.8
670	15.0	35.9	38.3	40.3	35.2	23.5	20.3	17.9	16.2
690	.	.	.	45.0	39.6	26.0	23.0	20.5	19.0
710	.	.	.	49.5	44.0	29.5	26.4	23.6	21.7
730	.	.	.	54.0	48.5	32.5	29.6	26.5	24.5
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.	.	.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

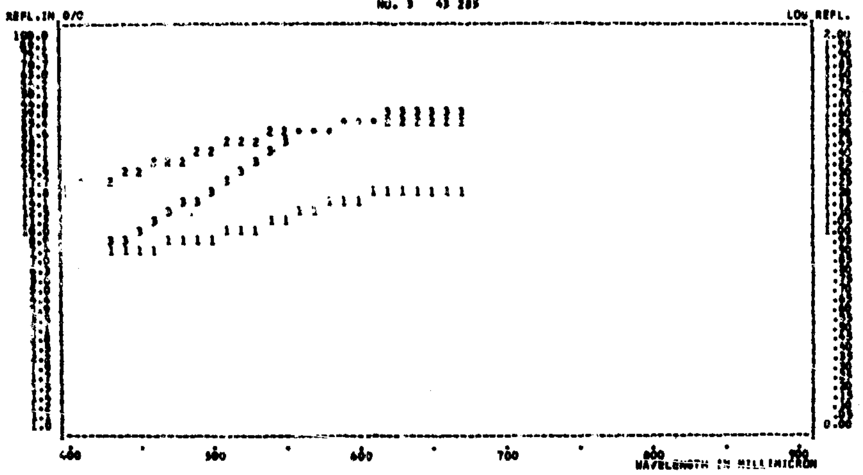
DIAGRAM 115
NO.1 CHESTNUT SOIL L, I 1 / TOLCJS590TP
NO.2 SIEROZEM TYPICAL / L, I 1 / TOLCJS590TP
NO.3 ERODED LATOSOL L, I 1 / TOLCJS590TP

DIAGRAM 116
NO.1 LIGHT-GRAY FOREST SOIL HEAVILY PODZOLIZED, AIR DRY / L, I 1 / ANDRVL58SPL
NO.2 ID. GLEYISH
NO.3 LIGHT-GRAY FOREST SOIL AIR-DRY / L, I 1 / ANDRVL58SPL

DIAGRAM 117
NO.1 GRAY FOREST SOIL AIR-DRY / L, I 1 / ANDRVL58SPL
NO.2 DARK-GRAY FOREST SOIL AIR-DRY / L, I 1 / ANDRVL58SPL
NO.3 CHERNOZEM PODZOLIZED, AIR-DRY / L, I 1 / ANDRVL58SPL

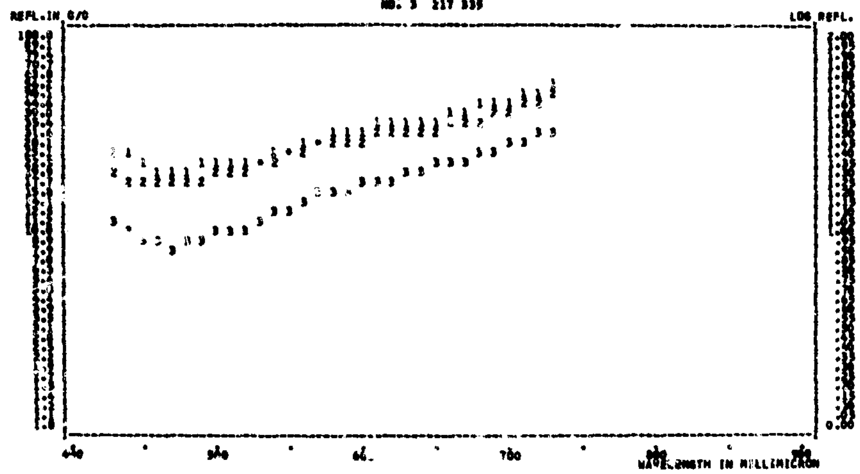
SPECTRAL REFLECTANCE CURVES

DIAGRAM 115



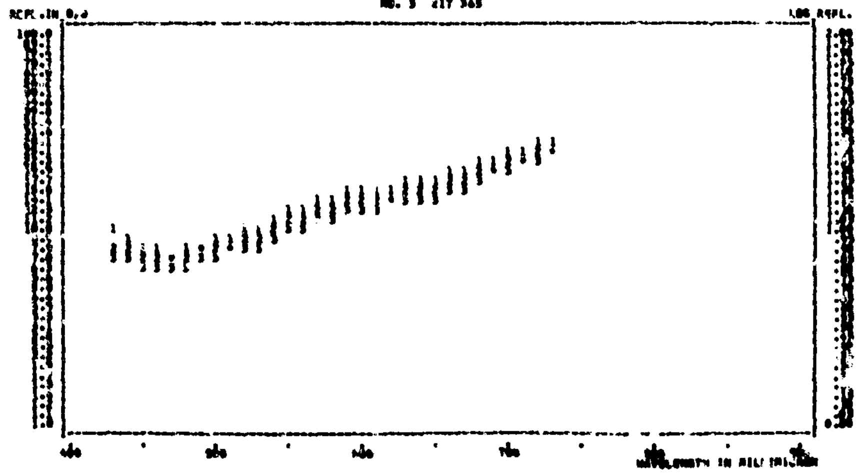
SPECTRAL REFLECTANCE CURVES

DIAGRAM 116



SPECTRAL REFLECTANCE CURVES

DIAGRAM 117



WAVE-LENGTH MMICR.	DIAGRAM 118 NO.1	NO.2	NO.3	DIAGRAM 119 NO.1	NO.2	NO.3	DIAGRAM 120 NO.1	NO.2	NO.3
400	.	.	.	.	.	.	.	.	.
430	18.5	9.5	.	8.0	6.7	5.5	.	.	.
450	16.0	8.0	.	7.0	6.4	5.0	.	.	.
470	14.9	7.3	.	6.5	6.0	4.7	.	.	.
490	16.5	8.5	.	7.6	6.6	4.9	.	.	.
510	17.8	9.1	.	8.5	7.0	5.4	.	.	.
530	19.0	10.0	.	9.0	7.7	5.7	.	.	.
550	20.5	11.8	.	11.0	9.4	6.7	.	.	.
570	22.0	13.7	.	12.6	10.8	7.8	.	.	.
590	23.0	14.8	.	13.7	11.7	8.4	.	.	.
610	24.0	15.5	.	14.5	12.1	8.8	.	.	.
630	25.2	17.0	.	15.5	12.5	9.5	.	.	.
650	26.2	17.8	.	16.3	13.2	10.0	.	.	.
670	29.0	20.0	.	18.3	14.7	11.5	.	.	.
690	34.5	23.0	.	21.0	17.0	13.0	.	.	.
710	39.5	26.3	.	23.8	19.0	14.7	.	.	.
730	45.0	30.0	.	27.0	21.4	16.1	.	.	.
750	.	.	.	.	.	.	.	.	.
770	.	.	.	.	.	.	.	.	.
790	.	.	.	.	.	.	.	.	.
810	.	.	.	.	.		.	.	.
830	.	.	.	.	.	.	.	.	.
850	.	.	.	.	.	.	.	.	.
870	.	.	.	.	.	.	.	.	.
890	.	.	.	.	.	.	.	.	.

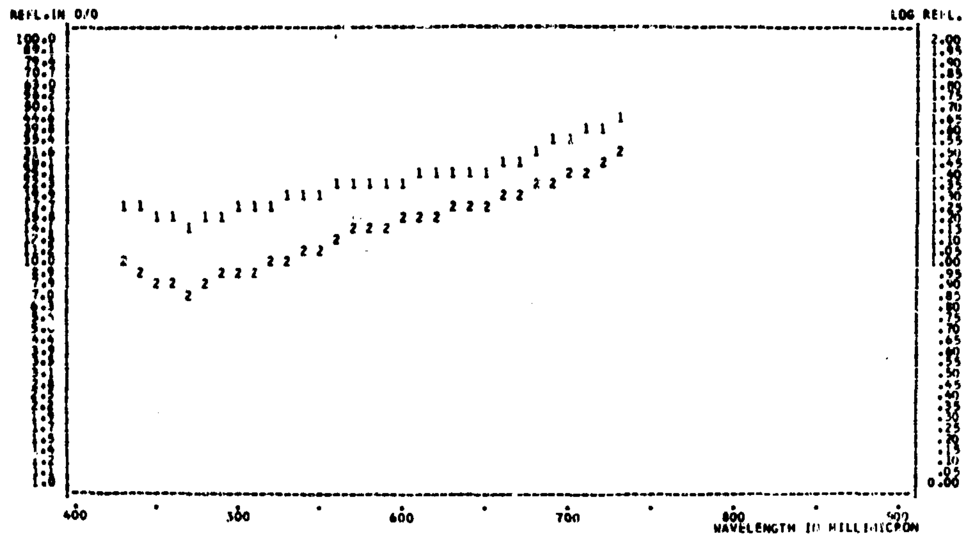
DIAGRAM 118
NO.1 LIGHT-GRAY FOREST SOIL DEEP, HEAVILY PODZOLIZED, MOISTURE CONTENT 2.95 PERCENT / L, I 1 / ANDRVL58SPL
NO.2 LIGHT-GRAY FOREST SOIL MOISTURE CONTENT 6.96 PERCENT / L, I 1 / ANDRVL58SPL

DIAGRAM 119
NO.1 GRAY FOREST SOIL MOISTURE CONTENT 7.63 PERCENT / L, I 1 ANDRVL58SPL
NO.2 DARK-GRAY FOREST SOIL MOISTURE CONTENT 9.52 PERCENT / L, I 1 / ANDRVL58SPL
NO.3 CHERNOZEM PODZOLIZED, MOISTURE CONTENT 10.0 PERCENT / L, I 1 / ANDRVL58SPL

SPECTRAL REFLECTANCE CURVES

DIAGRAM 118

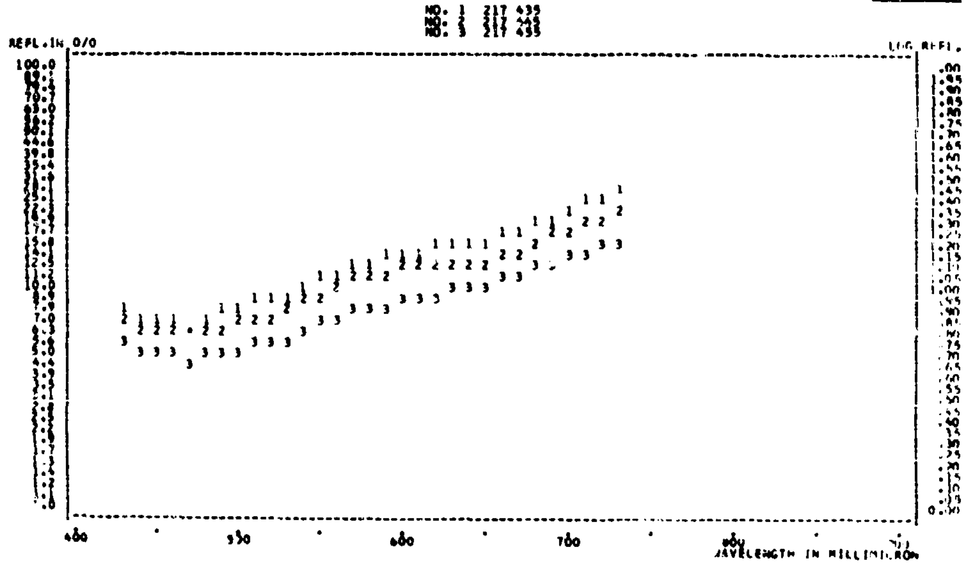
NO: 1 217 [illegible]
NO: 2 217 425



SPECTRAL REFLECTANCE CURVES

DIAGRAM 119

NO: 1 217 435
NO: 2 217 [illegible]
NO: 3 217 435



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This report is a comprehensive summary of a wealth of reflectance data published in the Russian literature that has been mostly unknown to Western researchers. The report describes: 1. the equipment and methodology used in making the measurements; 2. the major projects and project areas, and, 3. summarizes the results of the various measurements. Spectral reflectance data is tabulated and displayed in graphical form for a wide variety of surface vegetation - soil texture, moisture and composition - and for various types of rock weathering. A complete bibliography is included along with an index of geomorphological, pedological and botanical terms with Russian and Latin equivalents.

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